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FULLY BURDENED COST OF ENERGY ANALYSIS: A MODEL FOR MARINE CORPS SYSTEMS

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MONTEREY, CALIFORNIA

THESIS

**FULLY BURDENED COST OF ENERGY ANALYSIS:
A MODEL FOR MARINE CORPS SYSTEMS**

by

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March 2013

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This thesis uses a stochastic approach and Monte Carlo simulations to develop an operational, easy-to-adjust model for estimating the FBCEnergy for the USMC while considering the commodity cost of fuel, fuel delivery operation and support costs, fuel delivery asset depreciation, direct fuel infrastructure, indirect fuel infrastructure, environmental cost, and other platform unique costs such as force protection or regulatory compliance. The model and main findings of this thesis can be used in any future Analysis of Alternatives (AoA) performed before the acquisition of new weapon systems.

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FULLY BURDENED COST OF ENERGY ANALYSIS: A MODEL FOR MARINE CORPS SYSTEMS

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LIST OF ACRONYMS AND ABBREVIATIONS

ASD(OEPP)	Assistant Secretary of Defense for Operational Energy Plans and Programs
ASN(RD&A)	Assistant Secretary of the Navy (Research, Development, & Acquisition)
ACAT	Acquisition Category
ACV	Amphibious Combat Vehicle
ADP	Assured Delivery Price
AoA	Analysis of Alternatives
APUC	Average Procurement Unit Cost
CAC	Common Access Card
DAG	Defense Acquisition Guidebook
DAMIR	Defense Acquisition Management Information Retrieval
DESC	Defense Energy Support Center
DLA	Defense Logistics Agency
DoD	Department of Defense
DoDI	Department of Defense Instruction
DSB	Defense Science Board
DUSD(I&E)	Deputy Under Secretary of Defense (Installations & Environment)
E^2O	Expeditionary Energy Office
EN-ACQT	Naval Operational Energy in Acquisition Team
F-MTV	Family- Medium Tactical Vehicles
FB	Fuel Burden
FBCEnergy	Fully Burdened Cost of Energy
FBCFuel	Fully Burdened Cost of Fuel
FOB	Forward Operating Base
GAO	Government Accountability Office
HMMWV	High-Mobility Multipurpose Wheeled Vehicle
IOC	Initial Operational Capability
JLTV	Joint Light Tactical Vehicle
KPP	Key Performance Parameter
LAV	Light Armored Vehicle
LCC	Life-Cycle Cost
LCDR	Lieutenant Commander
LVSR	Logistic Vehicle System Replacement
M-ATV	Mine Resistant Ambush Protected All-Terrain Vehicle
MARCORSYSCOM	Marine Corps Systems Command

MBA	Master of Business Administration
MRAP	Mine Resistant Ambush Protected
MTVR	Medium Tactical Vehicle Replacement
NAVAIR	Naval Air Systems Command
NAVSEA	Naval Sea Systems Command
NDAA	National Defense Authorization Act
O&S	Operations & Support
OMB	Office of Management and Budget
OPTEMPO	Operational Tempo
OSD	Office of the Secretary of Defense
OSD(DA&M) &	Office of the Secretary of Defense (Director of Administration Management)
PEO	Program Executive Officer
SecDef	Secretary of Defense
SLE	Service Life Extension
SPAWAR	Space and Naval Warfare Systems Command
SRA	Scenario Route Apportionment
SYSCOM	Systems Command
TA-O	Tanker/Oiler
TBFDS	Tactical Bulk Fuel Delivery System
TCPT	Transportation Capacity Planning Tool
TOC	Total Ownership Cost
USD(AT&L)	Under Secretary of Defense (Acquisition, Technology, & Logistics)
USMC	United States Marine Corps
USN	United States Navy
VAMOSC	Visibility & Management of Operations & Support Costs

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I. INTRODUCTION

As federal budgets tighten and lessons learned from the wars in Iraq and Afghanistan are compiled, the Department of Defense (DoD) is revisiting cost-cutting measures; specifically, its dependence on fossil fuels. As such, the Office of the Assistant Secretary of the Navy for Research, Development, and Acquisition (ASN[RD&A]) directed in a memorandum dated June 2011 that energy-related factors must be considered in the acquisition process, as part of the life-cycle cost analysis and as part of the Analysis of Alternatives (AoA). In support of this perspective, DoD initiatives in energy efficiency call for a new methodology, calculating Fully Burdened Cost of Energy (FBCEnergy), rather than Fully Burdened Cost of Fuel (FBCFuel). Subsequently, Marine Corps Systems Command (MARCORSYSCOM) was directed to establish a method for calculating FBCEnergy for United States Marine Corps (USMC) terrestrial systems as part of the acquisition process. As directed in the *Defense Acquisition Guidebook* (Department of Defense [DoD], 2012):

> [FBCEnergy] estimates the energy-related costs to sustain specific pieces of equipment, including procurement of energy, the logistics needed to deliver it where and when needed, related infrastructure, and force protection for those logistics forces directly involved in energy delivery… [FBCEnergy] is meant to provide the acquisition process with a realistic, financial proxy for the fuel burden our forces will incur in the future battlespace. (Section 3.1.6)

This thesis provides a realistic and easily modified methodology for calculating FBCEnergy. This methodology can be used as part of an AoA for life-cycle cost estimation in the DoD acquisition process.

In the calculation of the FBCEnergy, the value of many critical variables, such as probability of loss, route length, vehicle speed, and the use of a specific vehicle are not known with certainty. However, by incorporating a stochastic approach, this thesis considers and develops a range of realistic values for those variables. This thesis calculates FBCEnergy using a simulation tool known as Monte Carlo simulation. The Government Accountability Office's (GAO's) *Cost Estimating Guide: Best Practices for Developing and Managing Capital Program Costs* (2009b) lists Monte Carlo simulation

among its best practices for determining cost risk and uncertainty. Monte Carlo simulation combines multiple stochastic inputs, such as route length or generator efficiency, to deliver a range, or distribution, of all potential FBCEnergy outcomes. The goal of our model is to provide a Monte Carlo simulation to the FBCEnergy analysis using Microsoft Excel without add-on applications (i.e., Crystal Ball and @Risk). This approach allows for the incorporation of risk analysis based on the probability of a future event occurring while ensuring compatibility with Marine Corps computing systems. Decisions can then be made with more complete information than if a single-point estimate was used.

The Monte Carlo-driven model in this simulation produces a range of FBCEnergy values for every link in the supply chain. The final product is the dollars-per-day value to operate a selected USMC terrestrial system for a given scenario, while accounting for the uncertainty and risk involved in that scenario.

The FBCEnergy model developed in this thesis can be used to estimate the dollars-per-day value of systems consuming fuel for mobility as well as for those systems that generate electricity. The fuel supply chain model used estimates the delivery cost of fuel as a function of location and demand for support of acquisition trade space decisions. The analysis in this thesis shows the benefit of a reduction in supply requirements when analyzing high-efficiency alternatives.

A. PURPOSE

The purpose of this thesis is to provide a working model that calculates an FBCEnergy estimate based on a short combat scenario. The FBCEnergy for the selected combat scenario calculates cost for both fossil fuels and electricity demand across 15 days. However, the model can be adjusted to incorporate changes in the combat scenario, making it a valuable tool for decision-making.

FBCEnergy provides complementary insights to total ownership costs. The model establishes a base for further refinement and research with regard to FBCEnergy and as an analytic input to a business case analysis. In compliance with the DAG, the model is used to "determine if the differences in energy demand and resupply costs are

significant enough to meaningfully influence the final choice of alternatives" (DoD, 2012, Section 3.1.6).

B. RESEARCH OBJECTIVES

The objective of the research is to create a methodology to comply with the guidance issued in the *DAG*, Section 3.1.6: Fully Burdened Cost of Delivered Energy, and meet some of the requirements of Item 3.6 Cost and Supply-Chain Studies in the October 2012 research proposal put forth by the Naval Postgraduate School titled *Multidisciplinary Energy Studies Support for USMC Expeditionary Energy Office.* (Hernandez, Amara, Nussbaum, & Palo, 2012)

Guidance issued in the *DAG* (DoD, 2012), Section 3.1.6: Fully Burdened Cost of Delivered Energy Policy, has the following requirements:

- [FBCEnergy] shall be applied in trade-off analyses conducted for all developmental Department of Defense (DoD) systems with end items that create a demand for energy in the battle space as an analytic input to business case analysis. This analysis is required as part of Total Ownership Cost calculations, but provides different, but complementary insights.
- [FBCEnergy] estimates shall be made and reported for all acquisition category (ACAT) I and II systems that will demand fuel or electric power in operations, and will be applied to all phases of acquisition, beginning with the preparation of the Analysis of Alternatives.
- Develop [FBCEnergy] estimates to sufficient fidelity to determine if the differences in energy demand and resupply costs are significant enough to meaningfully influence the final choice of alternatives.
- [FBCEnergy] estimates are based upon a range of operational scenarios of sufficient duration to account for demanded logistics and force protection with realistic and analytically defensible scenario and cost elements.
- The same scenarios used in the program's AoA shall be used and a simple mean average computed.
- Assumptions for fuel logistics must be consistent with service future force plans, analytic tools, planning, and costing methodologies
- The framework is oriented toward liquid fuels.
- The Services determine the appropriate level of apportionment.
- ADP [Assured Delivery Price] and operational demand determine [FBCEnergy].

This research also meets the following requirements described in the *Multidisciplinary Energy Studies Support for USMC Expeditionary Energy Office.* Item 3.6 Cost and Supply-Chain Studies requires researchers to;

- Model USMC supply chains to estimate the cost of fuel.as a function of location and demand, to support acquisition decisions.
- Develop cost estimates for acquisition decisions [that] depend on assumptions about the logistics networks associated with planning scenarios.
- The results can be used in trade-offs involved in requirements definition as well as in cost estimates for Analysis of Alternatives.
- [The] model [has] the capability to produce estimates of impact of supply requirements associated with operations and support in several units, depending on the decision to be supported.
- [The model] explores measures that reflect supply-chain vulnerability and force protection requirements. (Hernandez et al., 2012)

The research in this thesis meets all the above requirements. Additional requirements in the Naval Postgraduate School research guidance were not met because they were not consistent with an FBCEnergy analysis.

C. LIMITS OF RESEARCH

The breadth of an FBCEnergy analysis requires that any single study be limited in scope and depth. Since we sought to develop a methodological framework, data and scenario refinement were, as always, a challenge. The model is also limited to fuel delivery systems and does not currently have the capability to calculate the fully burdened cost of other supplies, such as materiel or the fuel itself.

Selected data inputs to the model were based on assumptions outlined in the Data Sources section of this thesis. When historical data were absent, we relied on analogy or expert opinion.

Due to the classified nature of Defense Planning Scenarios, an approved Analysis of Alternatives Scenario was not used. While the model is scenario driven and calculates FBCEnergy based on a specific scenario for a given system, the scenarios chosen were based on best assumptions and collaboration from stakeholders.

II. BACKGROUND

The DoD has had several initiatives to bring the FBCEnergy to the forefront of DoD efforts to increase the energy efficiency of DoD platforms. This section details these efforts and provides a case for a careful consideration of the FBCEnergy analysis before the acquisition of any new weapon systems.

A. DEFENSE SCIENCE BOARDS

The Defense Science Board (DSB) conducted two task forces aimed directly at the strategic implications of energy strategy and security. In 2001, the DSB released *More Capable Warfighting Through Reduced Fuel Burden,* which called for the DoD to incorporate what is now known as FBCEnergy. In 2008, the DSB Task Force on Energy Strategy released a report titled *More Fight–Less Fuel*, calling for the DoD to "accelerate efforts to implement energy efficiency Key Performance Parameters (KPPs) and use the [FBCFuel] to inform all acquisition trades and analyses about their energy consequences" (Defense Science Board [DSB], 2008, p. 5).

1. Defense Science Board Task Force's 2001 Report to Congress

In 1999, the Under Secretary of Defense for Acquisition, Logistics, and Technology (USD[AT&L]) recognized the need for increased fuel efficiency in DoD platforms. The USD(AT&L) instructed the DSB to form a task force to research the issue of DoD fuel costs and provide recommendations.

The second finding of the DSB Task Force was the first call to incorporate what is now known as the FBCEnergy in regard to the DoD's fuel use. Prior to the study, the DoD calculated its annual fuel costs based on the "standard price," including the purchasing price of the fuel from the world market and the Defense Energy Support Center's (DESC's) operating costs. What the "standard price" did not account for was what the individual Services had to pay to move the fuel from the DESC supply points to the end users. The DSB Task Force calculated that once these additional costs were accounted for, the burdened cost per gallon of fuel increased by approximately 1,500%. This calculated price was not based on combat scenarios but rather on delivering fuel

during peacetime operations. Additional variables (expenses) would have to be added to account for fuel delivery in more austere and hostile combat environments.

The DSB Task Force placed heavy emphasis on the logistic requirements for transporting and delivering fuel as a factor in determining the fully burdened cost. The Task Force report stated that logistics takes up "one third of DoD's budget and half of its personnel. Most of the tonnage delivered by logistics is fuel" (DSB, 2001, p. ES-3). This statement implies that fuel consumes a much larger and intangible portion of the DoD's efforts than is currently reflected in published fuel costs and figures.

The DSB Task Force's report (2001) should have served as a strong call to action for the DoD. However, shortly after the report was released, terrorists struck the World Trade Center and the Pentagon, and the U.S. embarked on the Global War on Terror. It is only years later when major combat operations are winding down that the DoD is once again able to analyze its fuel use and find ways to be more efficient.

2. The 2008 DSB Task Force's Findings and Recommendations

In 2006, the USD(AT&L) once again directed the DSB to assemble a task force to examine the DoD's Energy Strategy and Security. In 2008, the DSB Task Force released its report titled *More Fight–Less Fuel*. The Task Force looked at energy use in regard to both individual services and systems and also examined the security of the DoD's energy grid. Unlike previous studies and reports, the 2008 DSB Task Force was much more damning of the DoD's energy practices and policies.

Similar to previous studies, the Task Force came up with a list of findings and recommendations. Of the six Task Force findings, three are relevant to the discussion of FBCEnergy:

- Finding 1: The recommendations from the 2001 Defense Science Board Task Force Report *More Capable Warfighting Through Reduced Fuel Burden* have not been implemented.
- Finding 4: There are technologies available now to make DoD systems more energy efficient, but they are undervalued, slowing their implementation and resulting in future [science and technology] investments.

- Finding 5: There are many opportunities to reduce energy demand by changing wasteful operational practices and procedures. (DSB, 2008, pp. 3–4)

Of note, several members of the 2008 DSB Task Force were also present on the 2001 Task Force. Therefore, it is no surprise that the first finding of the Task Force was that little mind had been paid to their previous study. However, since the release of the 2008 Task Force report, the DoD has begun to implement recommendations from both this report and the 2001 report.

Finding 4 resulted from hearings on more than 100 technologies that addressed the energy efficiency of current and future DoD items and platforms. Because mission accomplishment and ease of use are of primary concern to both DoD acquisition personnel and end users, the Task Force should not have been surprised that a less than optimal level of attention was paid in regard to fuel efficiency.

Similar to the challenge addressed in Finding 4, Finding 5 discusses the need to change the culture of the DoD to become more energy conscious and strive towards efficiency. The report states:

> The ingrained belief that energy will always be cheap and plentiful must be replaced with the clear linkage between energy efficiency and operational success. The Task Force found the lack of understanding of this linkage to be the most significant barrier to addressing unnecessary and wasteful practices. (DSB, 2008, p. 65)

Based on their findings, the Task Force made five recommendations, three of which are relevant to the discussion of FBCEnergy:

- Recommendation 1: Accelerate efforts to implement energy efficiency Key Performance Parameters (KPPs) and use [FBCFuel] to inform all acquisition trades and analyses about their energy consequences, as recommended by the 2001 Task Force.
- Recommendation 4: Invest in energy efficient and alternative energy technologies to a level commensurate with their operational and financial value.
- Recommendation 5: Identify and exploit near-term opportunities to reduce energy use through policies and incentives that change operational procedures. (DSB, 2008, p. 5)

Unlike recommendations from previous studies and reports, several recommendations and their associated tasks have been implemented. The complete list of findings and recommendations from the 2008 DSB Task Force can be found in Appendix A.

3. Federal Regulation and DoD Policy

Many of the DSB's recommendation and findings regarding FBCFuel have been codified in law and implemented through policy. This section identifies those laws and policies.

a. Congress

In the Duncan Hunter National Defense Authorization Act (NDAA) of 2009 the 110th Congress created the foundational requirements for FBCFuel analysis. Section 332 outlines DoD analysis requirements and defines FBCFuel.

Congress tasked the Secretary of Defense (SecDef) with requiring "analyses and force planning processes [to] consider the requirements for, and vulnerabilities of, fuel logistics". (NDAA, 2009, Section 332 [a]) Congress directed the SecDef to develop and implement a methodology that enables fuel efficiency to be implemented as a KPP during requirements development. This requirement applies to modification of existing systems as well as the development of new fuel-consuming systems. Congress also required that the life-cycle cost analysis include the FBCFuel.

Congress also provides the first definition of FBCFuel. NDAA 2009 defines FBCFuel as "the commodity price for fuel plus the total cost of all personnel and assets required to move and, when necessary, protect the fuel from the point at which the fuel is received from the commercial supplier to the point of use" (NDAA, 2009, Section 332 [g]).

b. Secretary of Defense

In DoDD 5134.15, the Office of the Secretary of Defense, Director of Administration and Management (OSD[DA&M]), (2011) defined operational energy. The Department of the Navy used this definition as it further defined analysis

requirements for subordinate commands. The OSD(DA&M) defined operational energy as follows:

> The energy required for training, moving, and sustaining military forces and Weapons platforms for military operations. The term includes energy used by power systems, generators, logistics assets, and weapons platforms employed by military forces during training and in the field. Operational energy does not include the energy consumed by facilities on permanent DoD installations, with the exception of installations or missions supporting military operations. Operational energy does not include the fuel consumed by non-tactical vehicles. (OSD[DA&M], 2011, p. 7)

c. *Under Secretary of Defense for Acquisition, Technology, and Logistics*

The Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics (OUSD[AT&L]) broadened the requirement from FBCFuel to FBCEnergy in DoDI 5000.02 . Enclosure 7, paragraph 6, states, "the fully burdened cost of delivered energy shall be used in trade-off analysis conducted for all DoD tactical systems with end items that create a demand for energy" (Office of the Under Secretary of Defense [OUSD(AT&L)], 2008, p. 59).

d. *The Assistant Secretary of the Navy for Research, Development, and Acquisition*

The ASN(RD&A) (2011) gave FBCEnergy guidance to Systems Commands (SYSCOMs) in their memorandum titled *Energy Evaluation Factors in the Acquisition Process*. The ASN(RD&A) (2011) defines the purpose of calculating FBCEnergy as "to better understand the relative cost differences between various designs by contemplating the fuel demand and related logistics and force protection in operational environments" (ASN[RD&A], 2011, p. 2) ASN (RD&A) requires FBCEnergy calculations shall be included in program planning in the AoA phase to inform trade-off decisions and the selection of a preferred military solution.

The ASN(RD&A) (2011) continues to give specific guidance to SYSCOMs. It states, "[FBCEnergy] must be calculated using operational scenarios or use conditions specified in the program's AoA guidance … for both steady-state and

surge OPTEMPO [operational tempo].” Further, it directs MARCORSYSCOM to develop a uniform method for calculating FBCEnergy for terrestrial platforms.

The ASN(RD&A) (2011) requires the following cost estimation for FBCEnergy methodologies:

- standard commodity cost of fuel;
- service-owned fuel delivery asset operating cost, to include personnel;
- force protection required for fuel delivery; and
- depreciation of fuel delivery and force protection assets.

The ASN(RD&N) (2011) requires SYSCOM cost estimating directorates to consider FBCEnergy in the AoA, life-cycle cost estimate and program cost estimates. Milestone authority will only grant permission to proceed when FBCEnergy calculations are incorporated into the affordability targets. The FBCEnergy cost component of the affordability target will be managed as a KPP at Milestone A. Energy will be considered in each step of the Milestone decision process, especially Milestone B.

As a last point, the ASN(RD&A) (2011) requires that all major modernization efforts conduct an energy performance analysis that considers the feasibility of energy efficiency upgrades. The energy performance analysis should consider energy resupply rates, particularly in combat operations, to determine the military and financial value of retrofits.

e. Navy Operational Energy in Acquisition Team

The Navy Operational Energy in Acquisition Team (EN-ACQT) provides amplifying guidance on how and when FBCEnergy analysis should take place. EN-ACQT states AoAs shall consider alternatives that can improve energy efficiency and reduce FBCEnergy when energy usage is expected to exceed a currently undefined percentage of Total Ownership Cost (TOC). It also requires FBCEnergy be “weighed against similar/previous systems as a metric to demonstrate energy efficiencies and savings over the total life of the system” (Naval Operational Energy in Acquisition Team [EN-ACQT], 2012, p. 1). The document also requires the FBCEnergy analysis be compared to a baseline grounded in existing fielded systems.

f. Fully Burdened Cost of Fuel for the USMC

The two DSB Task Forces and their associated recommendations serve as a call to action in regard to DoD energy efficiency. Following the 2008 release of the DSB Task Force for Energy Security, the ASN(RD&A) (2011) released a memorandum that provided guidance "concerning the [Navy's] use of energy-related factors in acquisition planning, trade-off analyses, technology development, and competitive source selections for platforms and weapons systems" (ASN[RD&A], 2011, p.1). The memorandum directed that FBCEnergy be used in all future analyses of alternatives (AoAs) so that more informed decisions could be made in regard to the procurement of systems for the Navy. FBCEnergy shall be used as an independent variable when calculating total life-cycle cost estimations for comparative systems. This memorandum serves as the guidance for all Navy and Marine Corps Systems Commands (MARCORSYSCOM, Naval Air Systems Command [NAVAIR], Naval Sea Systems Command [NAVSEA], and Space and Naval Warfare Systems Command [SPAWAR]) and is a direct reflection of both the 2001 and 2008 DSB Task Forces. Further guidance and policy that has stemmed from both the DSB Task Forces and the ASN(RD&A) (2011) policy memorandum has led to the establishment of energy offices and programs within each of the respective Services. The Expeditionary Energy Office (E^2O) leads the Marine Corps' operational energy efforts. All of these programs are subordinate to the Office of the Assistant Secretary of Defense for Operational Energy Plans and Policy. This office is responsible for the oversight of all of the DoD's energy policies and organizations.

Since its inception, the United States Marine Corps (USMC) has been the nation's expeditionary fighting force. The Marines pride themselves on their ability to adapt, overcome, and thrive in austere locations on limited resources. However, just like all of the other Services, the Marines' dependency on fossil fuels has grown drastically in recent years.

According to the USMC Deputy Commandant for Installations and Logistics (2001), Life-Cycle Management Branch Requirements Section (LPC-1), in 2001, the average Marine infantry battalion had 64 Humvee variants. Today, that same

infantry battalion has 173 Mine-Resistant Ambush Protected (MRAP) vehicles and MRAP All-Terrain Vehicles (M-ATV). Because of this transition, vehicles are 3,000–5,000 pounds heavier apiece, decreasing fuel efficiency by 30% across the tactical fleet. Couple this decreased efficiency and subsequent increase in demand for fuel with the non-linear battlefield of today and that drastically detracts from the expeditionary capability of the USMC. The Commandant of the Marine Corps, General Amos stated,

> As a Corps, we have become more lethal, yet we have also become increasingly dependent on fossil fuel. Our growing demand for liquid logistics comes at a price. By tethering our operations to vulnerable supply lines, it degrades our expeditionary capabilities and ultimately puts Marines at risk. To maintain our lethal edge, we must change the way we use energy. (United States Marine Corps Expeditionary Energy Office [USMC E^2O], 2011, p. 3)

Therefore, the Marines are measuring the cost of fuel not just in dollars paid but also in the degradation of their expeditionary capabilities and the increased risk associated with longer and more vulnerable logistics trains.

4. Comparison of Methodologies

LCDR Scott Roscoe's 2010 master's thesis at the Naval Postgraduate School in Monterey, CA, titled *A Comparison of the Fully Burdened Cost of Fuel Methodologies Employed Across the Department of Defense* compares methodologies used by the individual services to derive FBCFuel and obtain similar estimates (Roscoe, 2010, p. 43) despite using vastly different methodologies. Roscoe's thesis concludes (or shows) that Service-specific methods obtain similar results in comparison to the USD(AT&L) FBCFuel calculator, version 7.0.

Roscoe's thesis also shows that stochastic and deterministic methods provide similar results. Roscoe's thesis identifies the Air Force model as deterministic and compares it to the stochastic methods used in the USD(AT&L) calculator. The results of the deterministic Air Force calculator were found to be within one standard deviation of the USD(AT&L) calculator (Roscoe, 2010, p. 38).

The third major finding in Roscoe's thesis is that a major driver of results variation is input data. Roscoe's thesis compares constant inputs in the individual models

to varying input assumptions in a single model. The results are evidence that changing the initial conditions causes a larger change in output results than is seen between the various models when inputs are constant (Roscoe, 2010, p. 43).

Roscoe's thesis acknowledges the validity of Service-specific models. The thesis stated that specialized FBCFuel methodologies have the potential to be the best way forward due to the unique structure of logistics in each Service (Roscoe, 2010, p. 44).

Most interestingly, Roscoe's thesis finds that the USD(AT&L) FBCFuel calculator, version 7.0, produces some irregularities. The calculator was run 100 times at 1,000 iterations of the Monte Carlo simulation. Roscoe's (2010) analysis produced the following anomalies:

- Less than Steady State ADP and FBCFuel,
- More than three standard deviations away from the mean
- Negative [results] (Roscoe, 2010, p. 36)

In addition, the calculator does not output as expected when the number of required escorts is increased. "When the number of escort assets, in this case F-16 fighters, was increased, the ADP and FBCFuel went down significantly" (Roscoe, 2010, p. 44). This result is contrary to what one might logically expect, including when the probability of interdiction is brought down to zero.

5. Importance of Fully Burdened Cost of Energy Analysis

Proper use of FBCEnergy analysis can increase combat effectiveness. FBCEnergy quantifies the logistical burden placed on the service in combat by creating a financial proxy for comparison of alternatives.

FBCEnergy is "used to inform the acquisition trade space by quantifying the per gallon price of fuel (or per kW [sic] price of electricity) used per day for two or more material solutions" (DoD, 2012, Section 3.1.6). The question remains as to the effect of these cost differences on DoD energy consumption, fossil fuel availability, TOC, and combat effectiveness.

Fuel consumption impacts the DoD in several different areas. FBCEnergy analysis is intended to influence DoD fuel consumption, fossil-fuel availability, TOC, cost estimates, and combat effectiveness. However, we show, FBCEnergy does not significantly impact fuel consumption, fossil fuel availability, or TOC.

a. Combat Effectiveness

FBCEnergy enhances combat effectiveness by providing the acquisition professional with information in order to make sound trade-space decisions. FBCEnergy delivers a financial proxy of energy demand, which can be used to quantify the impact of energy efficient alternatives on a unit's energy demand. The 2011 USMC Expeditionary Energy Strategy (USMC E^2O, 2011) highlights how visibility of a unit's energy demand and usage equates to combat effectiveness.

> For Marine commanders to increase combat effectiveness through energy efficiency and performance, they must be able to see the energy resource status of their unit at a given moment. This data will enable commanders to validate, manage, and adjust combat effective, energy-efficient operations. It will also inform our requirements development and acquisition process, providing critical data to focus materiel and non-materiel investments. Along with policy, doctrine, and training, the materiel solutions that give systems and platforms the ability to capture and report essential data are key enablers for this strategy. (USMC E^2O, 2011, p. 31)

By decreasing a unit's reliance on traditional fuel sources, its combat effectiveness increases. Instead of allocating resources to protect the logistic trains required to deliver fuel and other energy sources, those resources can be dedicated to other missions. Therefore, FBCEnergy takes into account not only the monetary requirements to deliver energy, but also the human capital associated with transportation and delivery. Having visibility of these requirements allows acquisition professionals to make informed decisions as to resource allocation and usage. However, there are more direct ways of measuring combat effectiveness than FBCEnergy affords. Efforts to quantify the additional days of combat or the decrease in the number of fuel convoys resulting from fuel efficiency would provide decision makers a more solid metric to base trade offs.

b. Total Ownership Costs

FBCEnergy is not intended to be a component of (TOC); it is intended to complement it. According to an August 2012 memorandum from the Assistant Secretary of Defense for Operational Energy Plans & Programs, "[FBCEnergy] is not additive to Total Ownership Costs, but rather reported beside it. While TOC estimates are based on total ("peace time") life of a system, [FBCEnergy] estimates are based on short combat scenarios" (DoD, 2012). FBCEnergy analysis is not applicable to TOC because combat scenarios represent only a small fraction of the total life cycle of a weapon system. FBCEnergy results will not provide information on TOC from energy efficiency improvements to a system because it is not intended to.

c. DoD Consumption

From a commodity cost perspective, the DoD is not significantly impacted by fuel costs. The commodity cost of fuel accounted for only 2.5–3% of the DoD's total budget, at a time when crude oil costs are near historic highs (The JASON Group, 2006). The JASON study (2006) analyzed the DoD from a commodity cost of fuel perspective so a fully burdened analysis may significantly increase the estimated impact fuel cost will have on the national defense budget due to potentially large multipliers from fuel delivery. However, since FBCEnergy analysis only analyzes combat scenarios, it cannot provide budgetary inputs because most of weapon system fuel consumption takes place in a peacetime environment.

DoD consumption does not have a significant effect on the market price of fuel. Although the JASON study (2006) found that the DoD accounts for 93% of federal consumption, the federal government accounts for only 1.9% of total U.S. fuel consumption. The DoD was not found to be a cost driver in any fuel markets.

d. Fossil-Fuel Availability

Fossil-fuel availability is one potential driver for increased scrutiny in energy cost estimation. It is apparent that fossil fuel is necessary for today's highly mechanized fighting forces. Fossil fuel, and in particular crude oil, will be readily available, at or near current prices, for the next 25 years and potentially beyond.

World oil supply is not, and will not, become a constraint. The JASON Group conducted an analysis of DoD fossil fuel availability in 2006. The JASON Group (2006) found that the world currently has 41 years of proven crude oil reserves. It also found that the constraint limiting proven reserves to 41 years is not global availability, but financial prudence. Oil producers simply will not spend the funds necessary to secure more reserves because of the low net present value of capital expended on projects beyond 40 years. Further, the JASON Group (2006) found that production and refining capacity could increase to match demand. It should be noted that the JASON Group's recommendations are founded on the premise that no major upheavals occur in the next quarter century, and if major upheavals occur, they will have unknown consequences.

If current U.S. production is maintained, the DoD will have no trouble acquiring fuel to operate despite the nation's dependence on foreign oil. Although the U.S. imports 63% of domestic consumption, ample quantities of fuel are available, at DoD consumption levels, from domestic sources. Since the DoD is responsible for less than 2% of the nation's fuel consumption, it is able to source its entire fuel requirements from a small portion of U.S. production. The JASON Group (2006) concluded DoD consumption could be provided from just two Gulf of Mexico oil platforms or a small fraction of California and Alaska production.

Domestic oil reserves may become a factor. The JASON Group (2006) found that if current production and consumption rates are maintained, U.S. oil reserves will be depleted in the next 12 years. Domestic production is largely dependent not only on the existence of new reserves but also on production costs. If domestic production costs are prohibitively higher than foreign production costs, less capital will be expended domestically to develop additional conventional reserves. Still, although North America has few proven conventional reserves, 30% of the world's unconventional oil is available in the form of tar sands and shale oil. The JASON Group (2006) estimates that a significant portion of these unconventional resources can be exploited at less than $70 per barrel (bbl), including environmental mitigation costs.

III. METHODOLOGY

In this section, we describe the methodology and data sources used for this thesis. The methodology is based on previous FBCFuel calculators issued by the USD(AT&L) with increased emphasis on displaying the uncertainty of results due to the uncertainty in input data.

We compare and contrast FBCFuel and FBCEnergy in the first portion of this section. Next, the scenario is defined and specific data sources are identified and justified in the Scenario and Data Sources sections, respectively. A brief overview of our calculations is provided in the Model Calculations section. The calculation and data sections are meant to serve as an outline for the reader. For a more detailed examination of our data and model, please refer to the appendices.

A. FULLY BURDENED COST OF FUEL TO FULLY BURDENED COST OF ENERGY

EN-ACQT (2012) requires SYSCOMs to ensure their FBCEnergy analysis includes fuel and electrical demands. The USD(AT&L) released updated guidance on FBCEnergy methodology in the fall of 2012 that was based largely on the FBCFuel methodology described in 2009 *DAG* (DoD, 2009). Our calculator takes this new guidance into account and follows the methodology outlined in the 2012 *DAG* (DoD, 2012, Section 3.1.6).

FBCEnergy is advancement in the concept originally termed FBCFuel. The main difference is that an FBCEnergy analysis does not include the steady-state scenario originally included in an FBCFuel analysis. The exclusion of a steady-state scenario and reorganizing of elements reduces the number of price elements from 14 to three.

B. THREE PRICE ELEMENTS

The FBCEnergy methodology consists of three price elements. An overview of these three elements was incorporated into the *DAG* (DoD, 2012) and is outlined in Table 1.

The three elements listed in Table 1 form a structured step-by-step guidance for methodology. Each FBCFuel element is provided below the FBCEnergy element to show the commonality of price elements between FBCFuel and FBCEnergy. The three FBCEnergy elements contain every one of the seven elements from the FBCFuel analysis.

Table 1. Summary of Price Elements to Apply within Each Scenario to Determine the Assured Delivery Price

Element #	Price Element	Burden Description
1 (FBCFuel 1)	**Fuel**	Most recent Defense Logistics Agency Energy (DLA Energy) "standard price" plus OMB-direct price inflation to the fiscal year of the scenario. In some cases, one may substitute a location-specific contract delivery price.
2	**Tactical Delivery Assets***	Includes all of the following:
(FBCFuel 2)	Fuel Delivery Operations and &Support (O&S) Price	Per gallon price of operating service-owned fuel delivery assets including the cost of military and civilian personnel dedicated to the fuel mission.
(FBCFuel 3)	Depreciation Price of Fuel Delivery Assets	Captures the decline in value of fuel delivery assets using straight-line depreciation over total service life. Combat losses due to attack or other loss (terrain, accident, etc.) should be captured as a fully depreciated vehicle.
(FBCFuel 4) & (FBCFuel 5) & (FBCFuel 6)	Infrastructure, environmental, and other miscellaneous costs over/above and distinct from the DLA Energy capitalized cost of fuel	Per gallon price of fuel infrastructure, regulatory compliance, tactical terminal operations, and other expenses as appropriate.
3 (FBCFuel 7)	**Security***	Potential per gallon price associated with delivering fuel, such as convoy escort

		and force protection. Includes the manpower, O&S, asset depreciation costs, and losses associated with force protection.
Note. These costs vary by Service and delivery method (ground, sea, air). The information in this table came from the *DAG* (DoD, 2009, p. 4; DoD, 2011, Section 3.1.6).		

The price elements are discussed in detail in the next sections. For ease of understanding, the elements are listed in the original seven FBCFuel elements. The following paragraphs outline each element and define which additional parameters apply to that element. A data source relevant to USMC systems is also provided.

1. Commodity Cost of Fuel

The *DAG* states to start with the Defense Energy Support Center (DESC) standard price for the appropriate type of fuel (DoD, 2012). The DESC was renamed Defense Logistics Agency Energy (DLA [Energy]) in 2010 as part of the We Are DLA initiative. We use the current name, DLA (Energy), for this thesis, except where directly quoting previous works.

Typically, the commodity cost of fuel for the appropriate fuel type was used in the FBCFuel analysis based on the current standard price. This technique ignores all variability in past data and any price trends. It simply assumes that the price of fuel will remain constant across the platform's service life. No additional input parameters are necessary to calculate the commodity cost of fuel.

Using the most recent standard price is prescribed for FBCEnergy analysis in *DAG* Section 3.1.6 (DoD, 2011). This price is then inflated to the date of Initial Operational Capability (IOC) or later, using the most recent OMB inflation factors for fuel price. This method causes inconsistencies in data normalization where fuel is inflated, but all other cost elements remain in current dollars.

2. Primary Fuel Delivery Asset Operations & Support Cost

The *DAG* identifies these costs as involved with operating service-owned fuel delivery assets such as fuel trucks (DoD, 2012). This includes the cost of military and civilian personnel dedicated to the fuel delivery mission.

Data are available to the USMC for most of these parameters. The number of days to deliver fuel and the LCC multiplier are scenario based. The operational scenario will determine the input data. The LCC and useful life for all acquisition programs is available through the Defense Acquisition Management Information Retrieval (DAMIR) system. O&S costs can be found in Visibility & Management of Operation & Support Cost (VAMOSC) and Transportation Capacity Planning Tool (TCPT) databases.

3. Depreciation Cost of Primary Fuel Delivery Assets

The *DAG* argues that although depreciation is not normally used in DoD analysis, it is included in FBCFuel because calculation of depreciation accounts for the capital loss of fuel delivery assets. Straight-line depreciation is prescribed (DoD, 2012).

4. Direct Fuel Infrastructure Operations and Support and Recapitalization Cost

The *DAG* methodology prescribes adding the cost of direct ground fuel infrastructure operation and support, including recapitalization cost (DAU, 2012). This should only be the infrastructure not operated by DLA (Energy). Items such as storage sites, fuel bladders, tanks, and hydrants are included in this element.

Direct fuel infrastructure O&S and recapitalization cost is directly entered into the USD(AT&L) calculator. For our analysis, we used $0.41 per gallon, which was used in the previous FBCFuel Amphibious Combat Vehicle (ACV) analysis conducted by Peter Bulanow of Group W (P. Bulanow, personal communication, October 2, 2012).

5. Indirect Fuel Infrastructure

This cost element relates to the O&S of nonfuel delivery assets that assist the fuel delivery mission. Per USD(AT&L) guidance, examples could be the cost of the base fire department that provides firefighting coverage for a fuel facility.

These data are also available at DUSD(I&E) and entered directly into the FBCEnergy calculator. For our analysis, we used $0.41 per gallon, which was used in the previous FBCFuel ACV analysis conducted by Peter Bulanow of Group W.

6. Environmental Cost

The *DAG* defines the environmental costs to include carbon emission permits and hazardous waste control (DoD, 2012). An addition of $0.10 per gallon based on European carbon trading credit prices is suggested. Roscoe (2010) determined that the $0.10 estimate is used by most Services. This estimate will be used here as well and can be input directly into the FBCFuel calculator.

7. Other Service & Platform Delivery Specific Costs

In the FBCEnergy analysis, this element is named Security. In all FBCFuel analyses we are aware of, the only costs accounted for in this element were security related. This element provides the most room for interpretation and also the most variability in analysis. The presence of escort vehicles is scenario dependent and the cost burden is often comparable to that of the delivery vehicle, so the analysis is sensitive to scenario choices.

According to the National Defense Authorization Act (NDAA) of 2009, force protection costs must be included. This includes operation and support costs, direct fuel cost, and depreciation costs of the escort platform. The FBCFuel calculator, version 7.1, accounted only for force protection in its parameters. The *DAG*, Section 3.1.6 (DoD, 2011) prescribes that "all of the costs considered in the second price element should also be considered for security assets." Since all costs are service and platform specific, it makes sense that individual Services would be tasked with this additional calculation. However, at this time we are unaware of any analysis that includes more than force protection in the Other Service & Platform Delivery Specific Costs element.

Our FBCEnergy model includes O&S costs, direct fuel costs, depreciation costs, direct infrastructure, indirect infrastructure, and environmental costs for escort vehicles. This is the first analysis, by any Service we are aware of, that meets the NDAA of 2009 and *DAG* 3.1.6 requirements.

Data for the Other Service & Platform Delivery Specific Costs element can be found using data sources already discussed. Total LCC of one escort vehicle, number of days one escort vehicle will be used in its lifetime, total LCC of one escort aircraft, and

number of days one escort aircraft will operate during its lifetime can all be derived from information present in DAMIR. The number of days to deliver fuel (round trip), LCC multiplier to account for surge usage of delivery vehicle, aircraft escort ratio (delivery vehicles per escort aircraft), and escort ratio (delivery vehicles per escort vehicle) are dependent on the scenario used to analyze the FBCFuel. Current tactical employment, combined with scenario-specific constraints, should be used to determine reasonable values for these parameters.

Table 2 outlines the data available for a USMC terrestrial system analysis and what cost element the data are used in. The table is provided for ease of use in future FBCEnergy analysis.

Table 2. Summary of USMC FBCEnergy Data Sources

Database	Data Available	Data Access	Location
DAMIR	Unit costs, service life	CAC & Access approval	http://www.acq.osd.mil/damir/
TCPT	Logistical vehicle fuel consumption and usage	CAC & Access approval	https://www.tcpt1.usmc.mil/tcpt/welcome.action
VAMOSC	O&S for USN and USMC platforms	CAC & Access approval	http://www.oscamtools.com/vamosc.htm
DUSD (I&E)	Unable to access	Unknown	http://www.acq.osd.mil/ie/
DLA (Energy)	Commodity cost of fuel	Open to public	http://www.desc.dla.mil/

C. SCENARIOS

We analyzed three different scenarios. Due to the classified nature of Defense Planning Scenarios, an approved AoA scenario was not used to ensure our thesis contained no secret information. While the model is scenario driven and calculates FBCEnergy based on a specific scenario for a given system, the scenarios chosen were based on best assumptions and collaboration from stakeholders. A major strength of our model is how easily it can be adapted to future scenarios that are based on Defense Planning Scenarios.

Figure 1 depicts the three scenarios. The calculator is capable of calculating four delivery elements in one scenario; however, to keep our analysis in line with scenarios

generally expected to be encountered by our fighting forces, a maximum of three delivery elements were used in any one scenario.

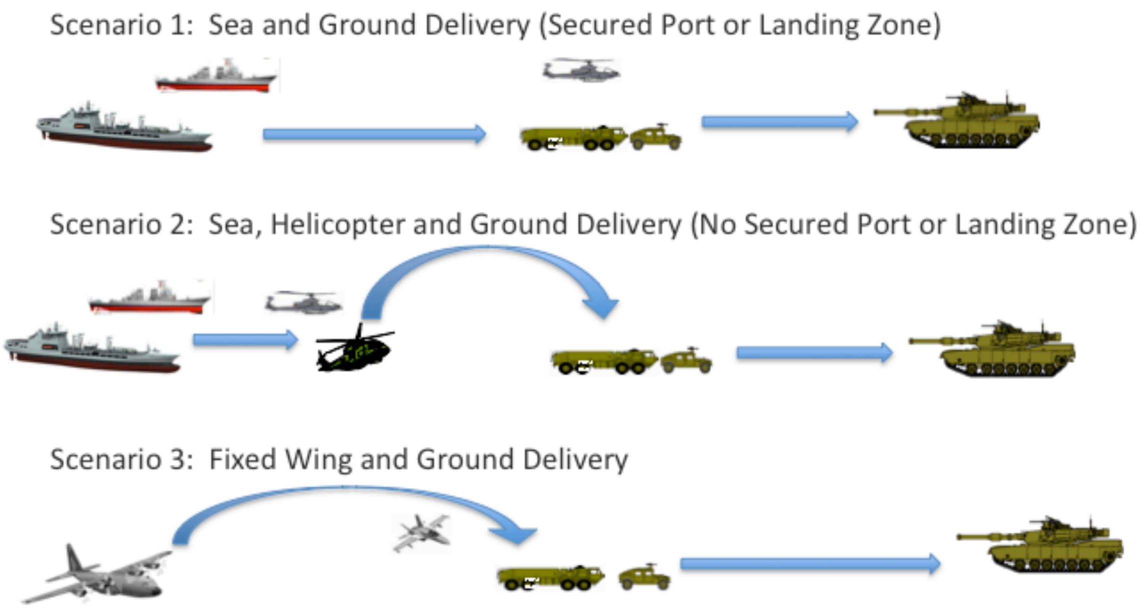

Figure 1. Energy Delivery Scenarios

Once FBCEnergy was calculated for each scenario, the statistical outputs were combined using an additional Monte Carlo simulation. The FBCEnergy for each scenario was reported as well as a weighted average based on the likelihood of executing each scenario. This thesis used a weighted average favoring Scenario 1. Scenario 1 was given a weight of 0.6, while Scenario 2 and Scenario 3 were given weights of 0.35 and 0.05, respectively. To retain the uncertainty shown by the distributions, Monte Carlo simulation was chosen over simply averaging the mean values.

1. Scenario 1: Sea and Ground Delivery (Secured Port or Landing Zone)

Scenario 1 is meant to outline the basic amphibious assault scenario. Here a Navy tanker/oiler (TA-O) supplies the fuel to Medium Tactical Vehicle Replacements (MTVR), which are offloaded at a port or landing site. The MTVRs then transport the fuel with ground escort for the entire route and a helicopter escort for 50% of the route. This simulates the convoy moving from the secured beach or port landing facility into a zone with a higher probability of enemy contact. This higher probability of enemy

contact creates the need for helicopter escort. The convoy completes the delivery of fuel to the Amphibious Combat Vehicle (ACV). For detailed information on scenario specifics, see Appendix B.

2. Scenario 2: Sea, Helicopter, and Ground Delivery (No Secured Port)

Scenario 2 is constructed to outline an amphibious assault scenario where direct offload of logistics vehicles is not feasible due to enemy threat or inhospitable terrain. A CH-53E heavy lift helicopter pulls fuel from a Navy TA-O and delivers the fuel to MTVRs. The MTVRs then transport the fuel with ground escort for the entire route. The convoy completes the delivery of fuel to the ACV. For detailed information on scenario specifics, see Appendix D.

3. Scenario 3: Fixed Wing and Ground Delivery

Scenario 3 is intended to show an extreme scenario where operations tempo has caused the ground combat element to outrun its logistical supply. A KC-130J pulls fuel from a DLA-Energy Depot and delivers it to a Forward Operating Base (FOB). The FOB is in a high-threat area that requires a fixed wing escort in the terminal area. The model only allocates the escort aircraft for the final one-tenth of the route. MTVRs then transport the fuel with ground escort for the entire route. The convoy completes the delivery of fuel to the ACV. For detailed information on scenario specifics, see Appendices B, D, and F.

IV. DATA INPUT

Statistical representation of the input data is entered directly into our model. The minimum (min), measure of central tendency, and maximum (max) values of the data, as well as standard deviation, lognormal parameter M, and lognormal parameter S, were required for data analyzed.

Our model lists a measure of central tendency in place of mean, median or mode. This is because the normal, lognormal, and uniform distributions require mean values, but the triangular distribution technically requires the mode. In our model, mode is representative of the most likely value of the selected data.

In many cases the analysis relies on expert opinion or only three data points are available. In these cases, standard deviation and the lognormal parameters are not used in the creation of the output distribution since they are not required values for a triangular distribution.

The model has the capacity to analyze a wide range of scenarios, based on the inputs provided. Selection of Air, Land, and Sea Delivery is achieved by entering the number of vehicles used. For instance, by selecting zero air delivery vehicles the air route is excluded and does not add to the fully burdened cost or the assured delivery price. Additionally, the probability of use input field for Ground Delivery and Escort assets allows the inclusion of additional uncertainty in the scenario. This enables the calculation of both types of vehicles in a single analysis. It is only used with land assets because this is the only place where the USMC has interchangeable fuel delivery assets. The model is also capable of selecting the percentage of route escorted, thus enabling the calculation of a scenario where the escort is required for only a portion of the delivery route as is typical of aviation escort use.

A. DATA SOURCES

1. Aerial Fuel Delivery Assets

USMC CH-53E and USMC KC-130J are the selected aerial fuel delivery vehicles. The CH-53E was chosen due to its sustained and proven heavy lift capacity.

Originally slated for replacement in FY2018 by the CH-53K (GAO, 2012) selected CH-53Es underwent a service life extension (SLE). This SLE is intended to keep the CH-53E fleet flying through FY2018, as research and development and budgetary hurdles prolonged the IOC of the CH-53K.

The CH-53E has the ability to deliver up to 2,400 gallons of fuel via an off-loadable, internally stored, hard-cased fuel bladder known as the Tactical Bulk Fuel Delivery System (TBFDS). TBFDS also has the ability to rapidly refuel both ground equipment and helicopters while still stored inside the CH-53E. This allows for decreased turnaround time on deck for the CH-53E. Figure 2 depicts a USMC CH-53E immediately following takeoff.

Figure 2. CH-53E Super Stallion (From Sepe, n.d.)

The KC-130J has the ability to deliver up to 10,218 gallons/69,480 lbs of fuel, either by aerial refueling or rapid ground refueling. Coupled with its ability to rapidly refuel ground vehicles and equipment, the KC-130J is able to take off and land from unimproved surfaces (roads, expeditionary airfields). These capabilities allow for quick distribution of fuel to both air and land vehicles in austere conditions. Figure 3 depicts a USMC KC-130 Hercules.

Figure 3. KC-130J Hercules (From McCullough, 2009)

2. Aerial Escorts

USMC AH-1Z/UH-1Y and F-35B aircraft were chosen to be the aerial escorts for energy delivery. The H-1 aircraft were chosen because of their versatility and reliability as armed escort aircraft. Additionally, UH-1s have the ability to serve as casualty evacuation aircraft should the need arise. The UH-1Y and the AH-1Z also have a multitude of similarities. Therefore, the model does not distinguish between the two aircraft. Instead, the input for the model is listed as “H-1.” A mixed section of USMC AH-1Z and UH-1Y aircraft are depicted in Figure 4.

The USMC AH-1 has been in service since 1967, while the UH-1 has been in service since 1969. Since then, both aircraft have undergone several upgrades and modifications in order to extend their service life. In 1996, the USMC signed a contract with Bell Helicopters to upgrade both the UH-1N and AH-1W. Instead of modifying the existing airframes, both Bell and the USMC decided to build completely new aircraft based on the proven successes of the UH-1N and the AH-1W. The UH-1Y and the AH-1Z entered service in 2008 and have an expected service life of 30 years.

Figure 4. AH-1Z Viper (Foreground) and UH-1Y Venom (From Bell Helicopter, n.d.)

The USMC variant of the Joint Strike Fighter, the F-35B, is expected to enter service in 2014, and is intended to eventually replace the F/A-18, AV-8B, and EA-6B. The F-35B was selected for the model as it is slated to be the sole tactical fixed wing aircraft for the foreseeable future and will serve as both a fighter and attack aircraft. The F-35B has the ability to serve as an escort aircraft for both ground fuel delivery assets and aerial fuel delivery assets. Figure 5 depicts the F-35B conducting a vertical landing.

Figure 5. F-35B Joint Strike Fighter Lightning II (From Lockheed Martin, 2011)

3. Ground Fuel Delivery Assets

USMC ground fuel delivery assets consist of the MTVR cargo, the Logistic Vehicle System Replacement (LVSR) tractor with bulk fuel delivery trailer, and the Family of Medium Tactical Vehicles (F-MTV). All assets were chosen because of their wide proliferation, adaptability, and proven combat capability.

The MTVR cargo is a seven-ton medium tactical vehicle that was the USMC's solution to the required lift shortfall of the five-ton F-MTV. The MTVR cargo has the ability to deliver 1,705 gallons of fuel over a wide variety of terrain. The MTVR cargo entered service in 2001 and has an expected service life of 22 years (USMC Corrosion Prevention and Control, 2012). Figure 6 depicts a convoy of armed MTVRs.

Figure 6. MTVR Convoy (From Medium Tactical Vehicle Replacement, 2012).

The LVSR tractor and associated trailer have the ability to deliver 5,000 gallons of fuel. The LVSR is the USMC's heavy tactical vehicle that entered service in 2008 and has an expected service life of 22 years (USMC CPAC, 2012). The LVSR can negotiate a wide variety of terrain but is more suited to improved and semi-improved surface roads. Figure 7 depicts an LVSR with a 5,000-gallon fuel tank.

Figure 7. LVSR (From Tack, 2009)

The specific F-MTV variant chosen was the M1091A1 fuel/water tanker. The M1091A1 is capable of transporting and distributing 1,500 gallons of fuel. The M1091A1 is not organic to the USMC but was chosen due to the fact that the Army makes a fair portion of combat fuel deliveries. The M1091A1 was introduced in 1999 and has an expected service life of 20 years. However, the XM1091 is slated to be the follow-on to the M1091A1 and is currently in the testing phase. Figure 8 depicts the XM1091 F-MTV fuel/water tanker.

Figure 8. F-MTV XM1091 Fuel Tanker (From XM1091, 1998).

4. Land Force Protection

Ground fuel delivery escort assets selected for the model were the Light Armored Vehicle (LAV-25), the High Mobility Multipurpose Wheeled Vehicle (HMMWV or "Humvee"), and the Mine-Resistant Ambush-Protected All-Terrain Vehicle (M-ATV). These vehicles provide armed protection to ground fuel delivery assets through kinetic firepower, sensors, and armed personnel.

The LAV-25 is fitted with a turret with 360° traverse, armed with an M242 25-mm chain gun with 420 rounds of 25-mm ammunition, a coaxial M240C machine gun mounted alongside the M242, and a pintle-mounted M240 G/B machine gun mounted on the turret roof. While the LAV-25 is considered the standard configuration for the LAV family, the vehicle can be reconfigured to serve in various roles depending on the mission. Figure 9 depicts the USMC LAV-25.

Figure 9. LAV-25 (From United States Defense Cooperation Agency, 2011)

The Humvee was selected based on its adaptability, versatility, and proliferation throughout the USMC and its proven combat capability. The combat variant of the Humvee was slated for replacement by the Joint Light Tactical Vehicle (JLTV). However, due to developmental delays and budgetary restrictions, the Humvee will remain in service for the foreseeable future. The current up-armored variant of the Humvee has proven to be less than cost effective as the increased weight has placed an added strain on the engine and frame. This added weight has caused an upsurge in operating and maintenance costs. Figure 10 depicts an armored Humvee.

Figure 10. HMMWV (From Armored Humvee, n.d.)

The M-ATV was chosen based on its versatility and maneuverability. The shortened wheelbase and reduced weight compared to other MRAPs have made it ideal for the uneven terrain in the mountains of Afghanistan. Additionally, the M-ATV offers the ballistic protection that neither the LAV-25 nor the Humvee have. Figure 11 depicts the USMC M-ATV.

Figure 11. M-ATV (From Curvin, 2011)

B. MONTE CARLO SIMULATION

The goal of our model is to provide a Monte Carlo simulation to the FBCEnergy analysis using Microsoft Excel without add-on applications (i.e., Crystal Ball and @Risk). The rationale behind this methodology is that most USMC computer systems, especially those in deployed or austere locations would not have access or rights to the add-on applications commonly used for Monte Carlo simulation.

The model allows the user to select from four different distributions in order to match data distribution based on individual data sets. The distributions are triangular, uniform, normal, and lognormal. These four distributions were chosen based on the GAO's *Cost Estimation and Assessment Guide*'s recommendations (GAO, 2009a).

Triangular distributions are used when data are limited. Triangular distributions are continuous probability distributions with a lower limit, upper limit, and mode. Typically, these distributions can be employed when expert opinion was used to gather data.

The uniform distribution is used when all intervals of the same length on the distribution's support are equally probable. The uniform distribution is typically used

when one data point is available, or a range of data is available, but each point is equally likely.

A normal distribution is used to describe random variables that are distributed symmetrically around a single mean value. Many natural systems are normally distributed. This distribution can be used when the underlying data are normally distributed.

The lognormal distribution is used when the logarithm of the underlying data is normally distributed. This distribution takes only positive real values. When multiple normally distributed systems are combined, often they assume a lognormal distribution. This distribution is used when the underlying data appear lognormal.

Refer to Appendix I for a more rigorous examination of the triangular, uniform, normal, and lognormal distributions. Appendix I includes mathematical summaries of the distributions and the equations used in the model. It also contains a derivation of the lognormal parameters M and S used in the calculator. This calculation enables the calculation of M and S without taking the logarithm of all the underlying data. We believe that this is a novel approach to the calculation of these parameters.

1. Model Calculations

The model breaks the calculations into the following five steps:

1. Cost Factors Calculation,
2. Scenario Route Apportionment Calculation,
3. Fuel Burden Calculation,
4. ADP Calculation, and
5. FBCEnergy Calculation.

a. Cost Factors

Separate cost factors are calculated for O&S, depreciation, loss, direct infrastructure, indirect infrastructure, and environmental costs. This is repeated for each vehicle in the logistics and security system. Each cost factor is expressed in dollars per hour ($\frac{\$}{hr}$). Appendix H is provided to help the reader understand the equations in this section.

O&S and loss cost factors are calculated using Monte Carlo simulation. Once data are entered and a distribution selected, the model creates a distribution-specific output for each cost factor using Excel's random number generator and the appropriate inverse transforms described in Appendix I. While O&S cost factors have a dedicated Monte Carlo engine, loss cost factors use the route length and probability of loss Monte Carlo engines to deliver variability.

O&S costs are calculated directly from the inputs provided; however, loss cost factors are derived from Equation 1. The model uses a simple conversion from years to hours. Therefore, the model assumes losses can only occur when operating the vehicle.

$$Loss\ Rate = P_L[APUC - Depreciation\ Rate(IOC_{AoA} - IOC_{Vehicle})]\ \left(\frac{\$}{hr}\right) \tag{1}$$

Infrastructure and environmental costs are point estimates and contain no variability. Indirect infrastructure and environmental costs are not significant cost drivers and can remain point estimates. Direct infrastructure costs should account for variability due to their potential to be significant cost drivers; however, detailed infrastructure analysis is beyond the scope of this analysis and data are not readily available.

Depreciation is calculated using a straight-line method as shown in Equation 2. This assumes the vehicle is depreciating when it is not operating.

$$Depreciation\ Rate = \frac{APUC}{Service\ Life}\ \left(\frac{\$}{hr}\right) \tag{2}$$

b. Scenario Route Apportionment

Each cost factor is multiplied by a Scenario Route Apportionment (SRA) to determine the cost apportioned to the fuel burden. Cost is apportioned based on the route length divided by vehicle speed and delivery capacity as shown in Equation 3. This yields an apportionment in hours per gallon and avoids rough estimation of apportionments.

$$SRA = \frac{Route\ Length}{Fuel\ Delivery\ Capaticy \cdot Vehicle\ Speed}\ \left(\frac{hrs}{gallon}\right) \tag{3}$$

An individual SRA is calculated for each delivery method with the notation outlined in Appendix H.

2. Fuel Burden

The Fuel Burden is the cost burden placed on the delivered fuel by each component of the logistics system. Cost burdens are added together with the commodity cost of the fuel to determine the ADP. A fuel burden is calculated for each delivery and escort method and is outlined by the notation in Appendix H.

Each fuel burden has slightly different cost drivers, and therefore, each burden needs to be calculated with a unique method; however, all are expressed in dollars per gallon $\left(\frac{\$}{gal}\right)$.

The delivery burdens are independent of the number of vehicles used since it is assumed each delivery vehicle is carrying a full load of fuel. Equation 4 calculates helicopter fuel burden.

$$FB_{H,D} = SRA_H \cdot \left(F_{O\&S,H,D} + F_{Depr,H,D} + F_{Loss,H,D} + F_{DirI,H,D} + F_{IndI,H,D} + F_{Envi,H,D}\right)\left(\frac{\$}{gal}\right) \quad (4)$$

Fixed Wing Delivery Fuel Burden is calculated in the equation 5.

$$FB_{FW,D} = SRA_{FW} \cdot \left(F_{O\&S,FW,D} + F_{Depr,FW,D} + F_{Loss,FW,D} + F_{DirI,FW,D} + F_{IndI,FW,D} + F_{Envi,FW,D}\right)\left(\frac{\$}{gal}\right) \quad (5)$$

The Land Delivery Fuel Burden takes a weighted average of each vehicle's cost drivers based on the vehicle's probability of use. This is done to remove model sensitivity based on delivery vehicle choice. Land Delivery Fuel Burden is calculated using equation 6, where P_{U,D_i} is defined as Delivery Land Vehicle Probability of Use.

$$FB_{L,D} = SRA_L \sum_{i=1}^{n}\left[\left(F_{O\&S,L,D_i} + F_{Depr,L,D_i} + F_{Loss,L,D_i} + F_{DirI,L,D_i} + F_{IndI,L,D_i} + F_{Envi,L,D_i}\right) \cdot P_{U,D_i}\right]\left(\frac{\$}{gal}\right) \quad (6)$$

Total Sea Delivery and Escort Fuel Burden are derived together, instead of individual delivery and escort burdens. The data available lead to this approach, and these items are out of the Marine Corps' area of interest. Total Sea Delivery and Escort Fuel Burden is calculated using equation 7.

$$FB_S = F_{O\&S,S} + F_{Depr,S} + F_{Loss,S} + F_{DirI,S} + F_{IndI,S} + F_{Envi,S}\left(\frac{\$}{gal}\right) \quad (7)$$

Escort fuel burdens are dependent on the number of vehicles used in the scenario because fuel delivery capacity does not increase when the number of escort vehicles increases. Total Helicopter Escort Fuel Burden is calculated using equation 8, where $R_{H,E/D}$ is the ratio of Helicopter Escort Aircraft to delivery vehicles.

$$FB_{H,E} = R_{H,E/D} \cdot SRA_H \cdot \left(F_{O\&S,H,E} + F_{Depr,H,E} + F_{Loss,H,E} + F_{DirI,H,E} + F_{IndI,H,E} + F_{Envi,H,E}\right)\left(\frac{\$}{gal}\right) \quad (8)$$

The Fixed Wing Escort Fuel Burden is calculated similarly to the helicopter escort burden. Total Fixed Wing Escort Fuel Burden is calculated in Equation 9, where $R_{FW,E/D}$ is the ratio of Fixed Wing Escort Aircraft to delivery vehicles.

$$FB_{FW,E} = R_{FW,E/D} \cdot SRA_{FW} \cdot \left(F_{O\&S,FW,E} + F_{Depr,FW,E} + F_{Loss,FW,E} + F_{DirI,FW,E} + F_{IndI,FW,E} + F_{Envi,FW,E}\right)\left(\frac{\$}{gal}\right) \tag{9}$$

The Land Escort Fuel Burdens are calculated using weighted averages based on the probability of usage inputs similar to the Land Delivery Fuel Burden. However, the Escort Burden is dependent on the number of delivery vehicles used since an increase in escort vehicles does not correspond with an increase in fuel delivered. Land Escort Fuel Burden is calculated using equation 10, where $R_{L,E/L,D}$ is the ratio of Escort Land Vehicles to Delivery Land Vehicles, and $P_{U,E}$ is Escort Land Vehicle Probability of Use.

$$FB_{L,E} = SRA_L \sum_{i=1}^{n}\left[R_{L,E/L,D} \cdot \left(F_{O\&S,L,E_i} + F_{Depr,L,E_i} + F_{Loss,L,E_i} + F_{DirI,L,E_i} + F_{IndI,L,E_i} + F_{Envi,L,E_i}\right) \cdot P_{U,E_i}\right]\left(\frac{\$}{gal}\right) \tag{10}$$

3. Total System Assured Delivery Price

The Total System Assured Delivery Price (ADP) is calculated by adding all the fuel burdens together. If a component of the system is not used in the scenario, the components fuel burden will be zero, so no additional scenario adjustment is necessary.

The calculation of ADP ignores the fuel burn of the vehicles in the system because it is part of O&S cost. The O&S and SRA are multiplied to account for fuel consumption based on the amount of time the asset is required for the fuel delivery mission.

The Total System Assured Delivery Price is calculated using equation 11.

$$ADP = FB_{H,D} + FB_{FW,D} + FB_{L,D} + FB_S + FB_{H,E} + FB_{FW,E} + FB_{L,E} \tag{11}$$

4. Fully Burdened Cost of Energy

The *DAG*, Section 3.1.6 (DoD, 2011) prescribes calculating FBCEnergy by multiplying the system’s fuel demand by the ADP. This causes the first element in the fuel delivery system to be burdened by the fuel burdens of the rest of the system. If this method is used the cost of the land delivery systems that take fuel from the ship to the

combat vehicle would be included as a burden on the ship's fuel. The ship does not receive fuel from the truck, but instead, receives fuel from the DLA (Energy) depot or port. Including the entire system's burden to every component in the system is inaccurate.

In this thesis, FBCEnergy is calculated for each element in the fuel delivery system using the ADP of each element. The increase in ADP is only applied to subsequent vehicles that come after in the fuel supply chain. The following sections explain this process and the rest of our methodology.

a. AoA Vehicle Fuel Consumption

The consumptions of the AoA vehicle are calculated in two parts. The first is the consumption of fuel for locomotion, and the second is the consumption of fuel for electrical power generation. This is intended to allow for the inclusion of on board vehicle power or the calculation of standalone electrical generators. Once the AoA's fuel consumption is calculated, it drives the fuel consumption for the rest of the delivery system. The AoA vehicle's fuel consumption is calculated using Equation 12.

$$FC_{AoA} = \frac{Missions\ per\ day * Vehicles\ on\ Mission * Mission\ Length}{Vehicle\ Fuel\ Demand} + \frac{Electrical\ Demand}{Generator\ Efficiency}\left(\frac{gal}{day}\right) \tag{12}$$

b. Delivery and Escort Element Fuel Consumption

The delivery and escort element fuel consumption is calculated in three steps. First, the time required to deliver fuel is calculated. Second, the number of trips required to deliver the fuel consumed by the AoA vehicles is determined. Finally, the delivery or escort vehicle's fuel consumption is calculated.

The route time is calculated by dividing the route length by the route speed. This determines the amount of time the delivery vehicle spends delivering fuel for the AoA vehicle. The escort vehicles are then attached to this delivery time. This accounts for aviation assets flying much faster than the ground convoys but still being present for the entire delivery mission. The ability to input a percentage of route escorted is provided to account for situations where only a portion of the convoy's route is escorted.

The number of trips required to deliver the AoA fuel is calculated by dividing the AoA fuel consumption by the fuel delivery capacity of the delivery element.

Finally, the delivery or escort vehicle's fuel consumption is calculated by multiplying the route time by the vehicle's fuel demand multiplied by the number of trips. This is expressed in equation 13.

$$FC_{D\&E} = Route\ time * Fuel\ Demand * Deliveries\ required \tag{13}$$

c. *Element ADP*

Each element in the delivery system is burdened by the elements that precede it in the system. Figure 12 shows how each element is sequenced in the model and Figure 13 shows this sequence for Scenario 1. In Scenario 1, we use only Elements 1 and 2; Element 1 is Sea Delivery, and Element 2 is Ground Delivery. For Scenario 1, the Sea Delivery ADP is equal to the commodity cost of fuel because the ships receive fuel from DLA (Energy). The ADP of the Ground Delivery includes the burden of the Sea Delivery and Escort because the model assumes that the fuel burned by the Ground Delivery assets was received from the ship. The AoA vehicle's ADP includes the burden of the Sea Delivery and Ground Delivery elements. This is the ADP commonly referred to in the *DAG* guidance (DoD, 2011).

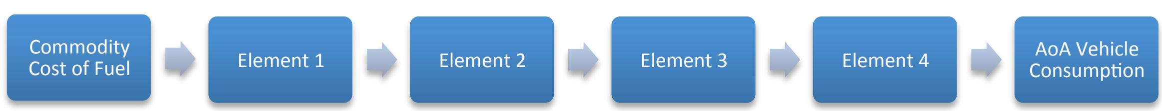

Figure 12. Model ADP Sequence

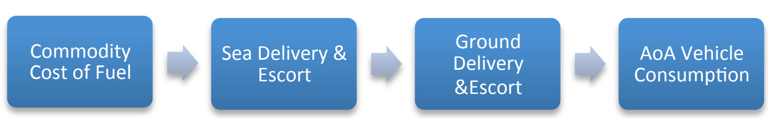

Figure 13. Scenario 1 ADP Sequence

d. Fully Burdened Cost of Energy

The cost of delivering energy to each element is calculated using the element's ADP and fuel consumption. Each Delivery & Escort element is calculated by multiplying its individual ADP by the element's fuel consumption. The result is expressed in dollars per day. The sum of the cost of each element is calculated to determine the FBCEnergy.

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V. RESULTS

This section presents and discusses FBCEnergy and ADP results from the analysis of the ACV. The scenario used here was based on a theoretical scenario, not an AoA or Defense Planning Scenario. A theoretical scenario was used to avoid releasing any classified or secret data. Results are highly scenario dependent; therefore, actual FBCEnergy numbers may differ from those presented here.

We present only Scenario 1 because it is the most likely scenario for the USMC. For a complete description of the model inputs and available outputs see Appendix B through G.

A. ASSURED DELIVERY PRICE

The ADP was calculated for both fuel and electricity generated. ADP-F represents the cost of delivered fuel to the ACV in dollars per gallon. ADP-E represents the price of delivered fuel in dollars per kWhr for a generator co-located with the ACV. ADP-E can be used for cost comparison to alternative power generation such as solar cells.

We calculated Total System ADP for delivered fuel. Figure 14 displays the Total System ADP-F for Scenario 1. This histogram is an output from the Monte Carlo simulator created for this thesis. It is presented because Scenario 1 is the most likely scenario for the USMC. Figure 14 shows that the cost of delivered fuel to Marine Corps systems is likely to be between $16.22 and $19.87 per gallon.

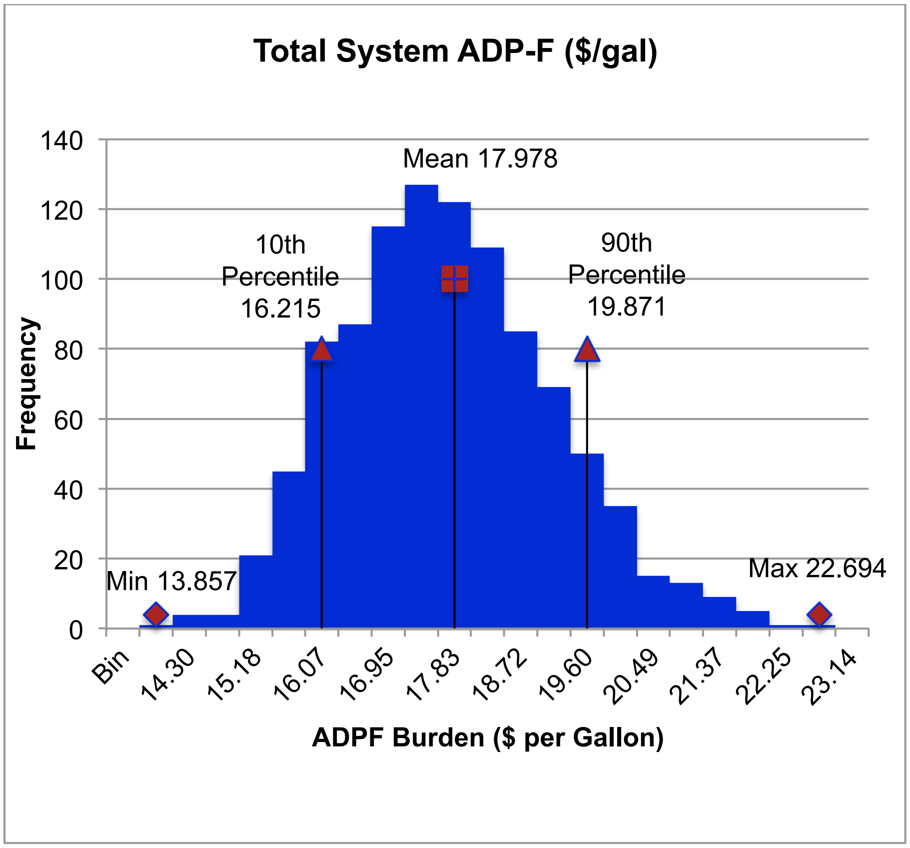

Figure 14. Scenario 1 Total System ADP-Fuel ($/gal)

Total System ADP for delivered electricity was also calculated. Figure 15 displays the Total System ADP-E for Scenario 1. It shows that electricity generation from fossil fuel in combat will likely cost between $1.77 and $2.76 per kWhr when fuel is delivered by USMC logistical systems. This value should be used only when comparing alternative energy source costs that have also been fully burdened using analysis techniques similar to the ones in this thesis.

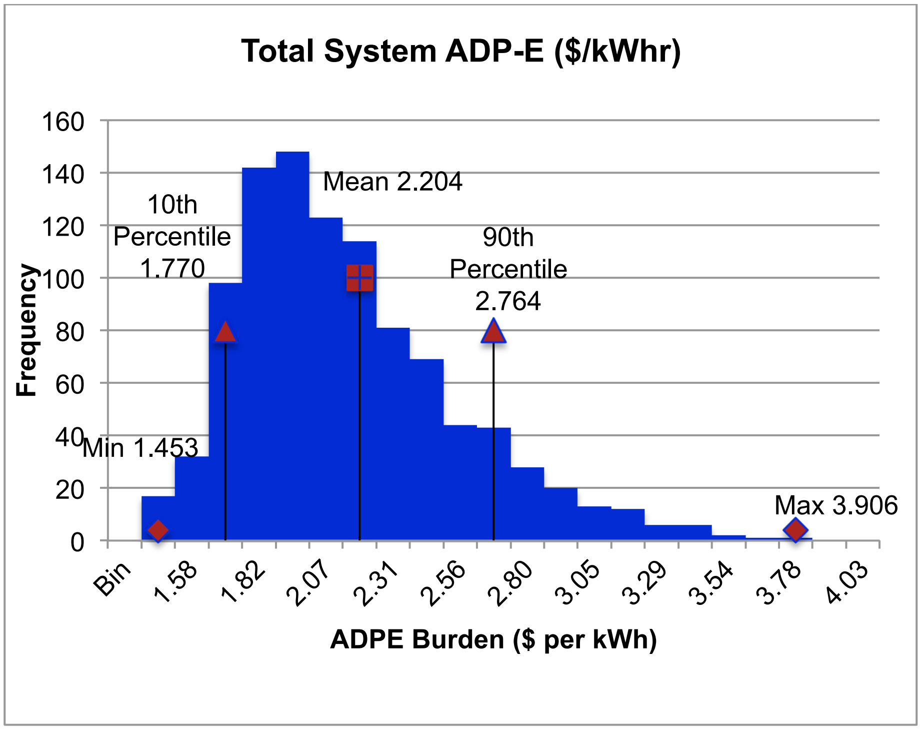

Figure 15. Scenario 1 Total System ADP-Energy ($/kWhr)

Each element of the fuel delivery system was analyzed to determine its impact on Total System ADP. Figure 16 shows each element's average contribution to system ADP for delivered fuel. The Navy Sea Delivery element had the greatest impact on a per gallon basis. The Land Delivery and Escorts combine to add almost as much burden as the Sea Delivery assets. The Helicopter Escorts in the scenario represent a similar burden as the Land Escorts; however, caution should be used when interpreting this within the context of the scenario. In this scenario, only two helicopters were present and provided escort for only 50% of the route. In comparison to the four Ground Escorts used for the entire route, it can be shown that Helicopter Escorts represent four times the burden as Ground Escorts on a per escort per mile basis.

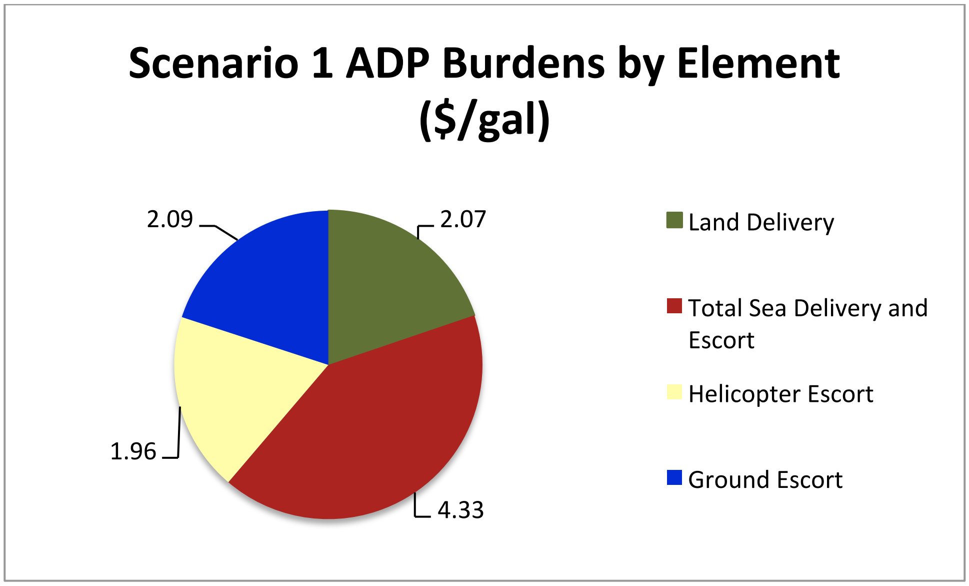

Figure 16. Scenario 1 ADP Burdens By Element ($/gal)

B. FULLY BURDENED COST OF ENERGY

FBCEnergy was calculated for each individual scenario, and a weighted average of the scenarios was calculated using Monte Carlo simulation.

FBCEnergy was found to have a weighted average of $37,370.09 per day and a median of $36,092.51 per day. The most likely value for FBCEnergy in this scenario is, therefore, the median value of $36,092.51. Eighty percent of the probable values fall within a range from $26,223.13 and $50,567.98. This is shown graphically in Figure 17. Figure 17 is a histogram created using the Microsoft Excel–generated Monte Carlo simulator created for this thesis.

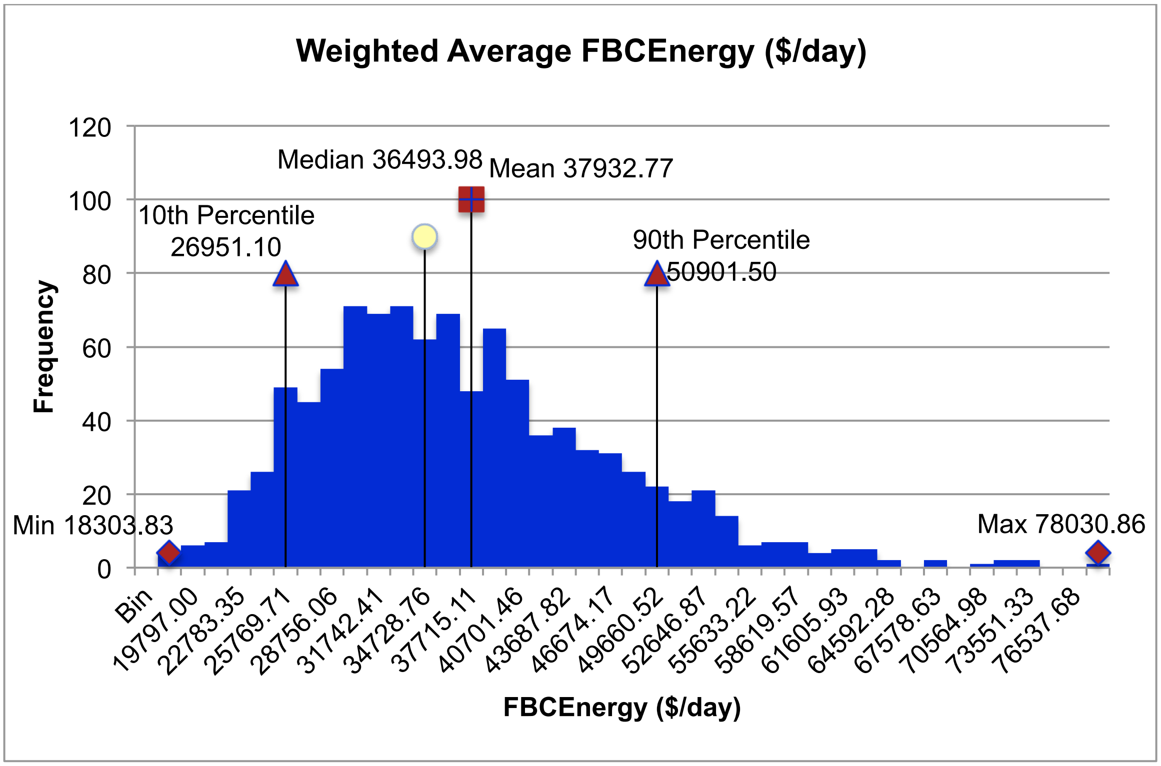

Figure 17. Weighted Average FBCEnergy ($/day)

FBCEnergy results are highly scenario dependent. This is shown in Figure 18. Of the three scenarios used in this thesis, Scenario 1 and Scenario 2 were similar in composition and results. Scenario 2 essentially added a short CH-53E delivery leg into the fuel delivery system. The corresponding effect on FBCEnergy was small. Scenario 3 utilized a KC-130J with an F-35B escort that became the major cost driver and resulted in a significant increase in Scenario 3's FBCEnergy. The weighted average is only slightly higher than the Scenario 1 and Scenario 2 values because Scenario 3 was only given a 5% weight in the model due to its unlikely occurrence for USMC fuel delivery.

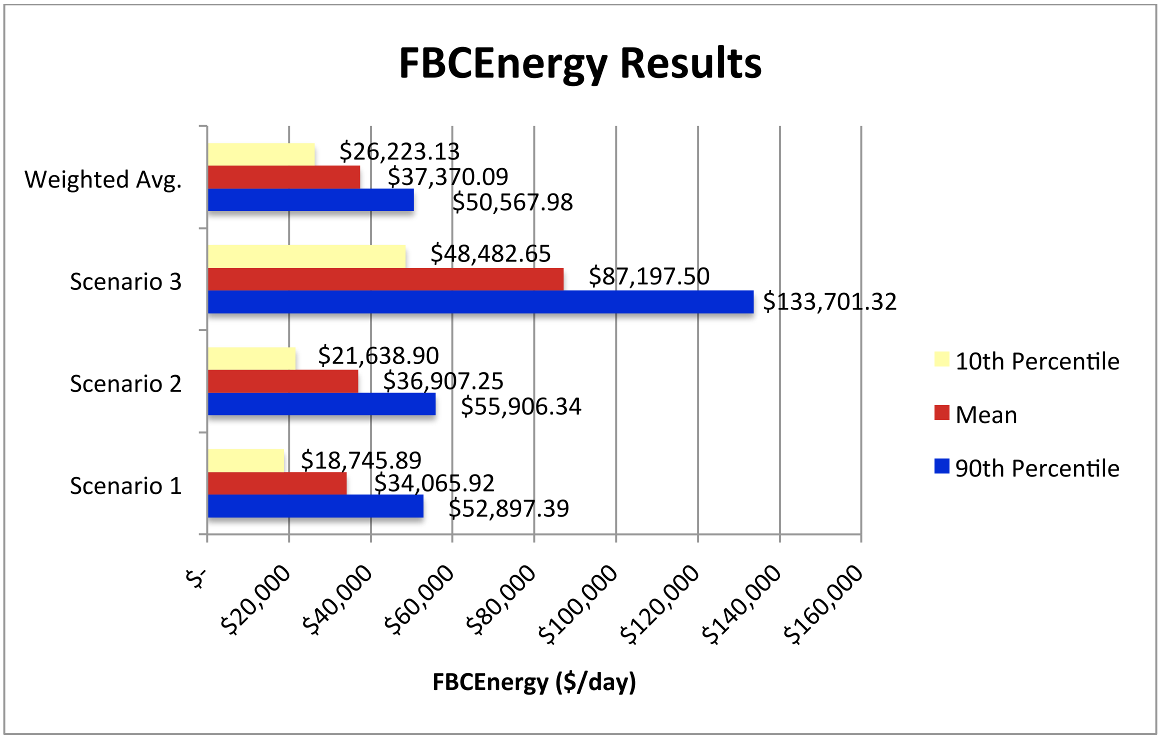

Figure 18. FBCEnergy Results

Scenario 1 was also analyzed to determine the greatest drivers of overall cost. As shown in Figure 19, in this scenario the main driver of FBCE was the ACV. This is to be expected since the ACV drives the fuel demand. Each element's FBCEnergy is calculated by multiplying its ADP by only the fuel consumption traceable to the ACV. In contrast, the ACV is burdened by all other elements and all of its fuel consumption is included. Because only a small portion of the Navy's fuel consumption can be attributed to a single combat system, the Sea Delivery and Sea Escort have a small contribution to FBCEnergy despite having a major impact on ADP. For these reasons, it is expected that the combat vehicle being analyzed will normally be the largest driver of energy costs.

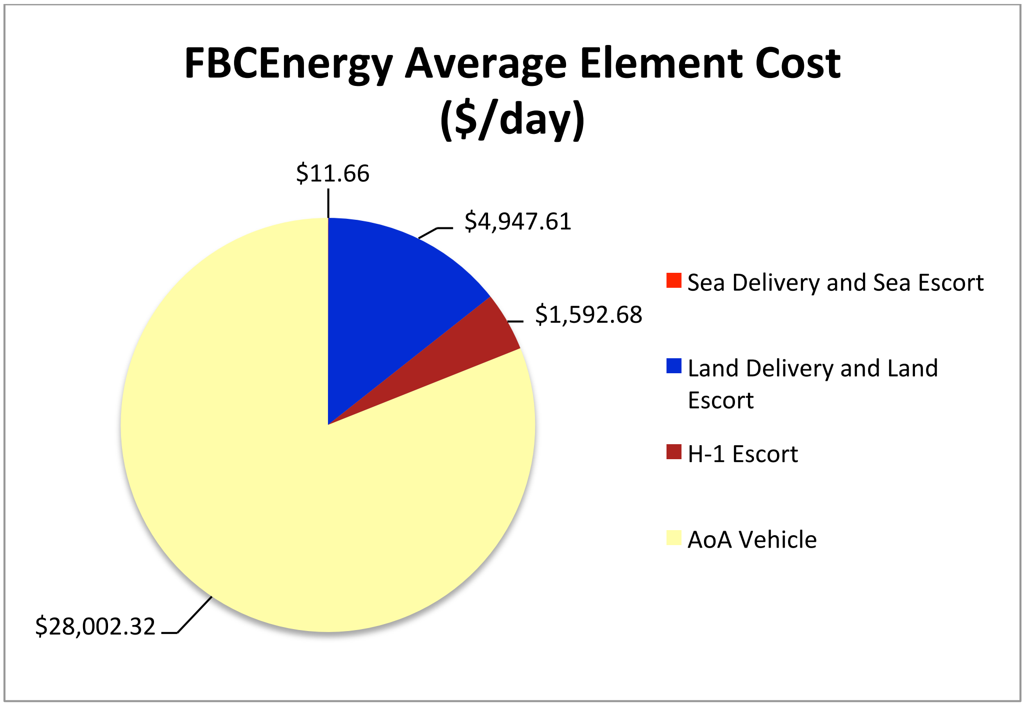

Figure 19. FBCEnergy Average Element Cost ($/day)

This should not be interpreted as saying that Sea Delivery assets have negligible impact on Marine Corps fuel burdens. The rest of the system does have a significant influence on the AoA vehicle's cost burden. In this scenario, the FBCEnergy of the AoA vehicle would be approximately half of the $28,002.32 per day shown without Sea Delivery as part of the system. Removal of Sea Delivery would remove roughly half of the ADP increase and so the cost of fuel for the AoA vehicle would cost half as much, even when consumption is held constant.

The results outlined here show that every element in the fuel delivery system has a significant impact on the FBCEnergy of an AoA vehicle. Reducing cost in elements at the beginning of the fuel delivery chain will have the greatest effect on the system as a whole because the cost of fuel consumed will be reduced for every element that follows.

C. SENSITIVITY ANALYSIS

The model was tested for robustness to any changes in input data within what are considered realistic, normal ranges. A sensitivity analysis was completed for each input in the model to ensure any change in an input variable had a logical effect on output

results. The model was also reviewed to ensure changes in outputs were proportional to input changes. Finally, the model was analyzed to determine significant drivers of ADP and FBCEnergy cost as well as cost variability. This section outlines that analysis.

Scenario 1 was used as the baseline for comparison. Each time an input variable was changed it was compared to Scenario 1 holding all other input variables constant. Every variable change had a reasonable outcome when compared to the baseline. When increasing variables such as route length, probability of loss, or delivery vehicle fuel demand an appropriate increase in ADP as well FBCEnergy was observed. The model behaved as designed and handled a wide variety of inputs while still providing reasonable estimates.

FBCEnergy was not significantly dependent on one particular variable. The stability of the model is due, in part, to the model's requirement for a vast number of inputs. Our FBCEnergy model requires 156 USMC weapon system inputs and 104 scenario specific inputs for a total of required 260 data inputs. These inputs can increase based on the type of distribution selected for the random variable generators. The type of distribution does have an impact on the range of FBCEnergy and ADP results. Therefore, care needs to be taken to ensure that the distribution selected matches the data modeled.

The main drivers of FBCEnergy were found to be commodity cost of fuel, mission and route length, AoA vehicle fuel efficiency, aviation escort ratio and percentage of route escorted. Of these, the commodity cost of fuel had the largest effect. Commodity cost of fuel impacts every element of the fuel delivery system as it is the initial input in the fuel supply chain. All other inputs have an effect only on the element that was changed and elements further down the supply chain. This minimizes the effect that changes such as delivery vehicle fuel efficiency have on the entire system. Aviation assets are also a major cost driver because of their high O&S costs as well as fuel consumption compared to other elements in the fuel delivery system.

The large range in FBCEnergy results for a given scenario is driven by route length and mission length variability. When these random variable inputs were reduced to point estimates the range of FBCEnergy decreased from $33,599 to $6,862 ($FY2012). The baseline inputs for route length and mission length were left as random variables with a large range to simulate actual missions USMC forces are likely to encounter. Any scenario would involve missions of varying length and logistical supply lines that expand as the operating force penetrates deeper into enemy territory.

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VI. CONCLUSIONS AND RECOMMENDATIONS

This section outlines the conclusion of our thesis and the subsequent recommendations. We also included a section for areas of further research.

A. CONCLUSIONS

This thesis develops an operational model for estimating FBCEnergy as part of the acquisition process of terrestrial systems for USMC. Our work is in response to the recent DoD initiatives in energy efficiency that call for a new methodology that requires calculating Fully Burdened Cost of Energy (FBCEnergy) rather than Fully Burdened Cost of Fuel (FBCFuel).

The model proposed in this thesis incorporates a stochastic, Monte Carlo simulation approach, and it is easy to adjust to new scenarios. Based on the scenarios considered, this thesis found the ACV to have an FBCEnergy of $36,493.98 ($/day), an ADP-Fuel of $17.98 ($/gallon) and an ADP-Electricity of $2.20 ($/kWh). The model developed in this thesis, as well as the main findings, can be used as part of analysis of combat systems in future AoAs.

The specific results delivered in this thesis are to be interpreted with caution because of the unclassified scenarios used and the limited applicability of any FBCEnergy analysis. However, the model developed in this thesis can be easily adjusted to incorporate any realistic changes in the scenarios analyzed.

Our main recommendation is to use FBCEnergy only when analyzing distinctly different systems prior to Milestone A. Analyses must also use consistent commodity cost of fuel and scenario assumptions to yield useful comparison.

Decision makers must exercise caution before drawing conclusions from FBCEnergy or ADP estimates. FBCEnergy is most useful when comparing distinctly different systems prior to Milestone A. Both FBCEnergy and ADP estimates have large ranges due to the uncertainties in the underlying data. The estimates are also highly sensitive to scenario assumptions and the commodity cost of fuel. Decisions about the AoA vehicle do not affect ADP in any way.

FBCEnergy is most useful when comparing distinctly different systems prior to Milestone A. The apparent effect of energy efficiency gains is minimized when looking through the lens of an FBCEnergy analysis. For instance, when the fuel efficiency of the ACV was increased by 33% the FBCEnergy decreased by only 21%. The energy efficiency gain is minimized because the efficiency increase affects only the AoA vehicle while the rest of the system remains constant. This minimization may cause decision makers to marginalize efficiency initiatives when evaluating alternatives in programs past Milestone A.

When analyzing two distinctly different materiel solutions, prior to Milestone A, FBCEnergy may be useful by providing a financial proxy for comparison. FBCEnergy enables a comparison of distinctly different systems, such as a ground combat vehicle and an aviation asset, by providing a single measure of the fuel burden the different fuel delivery systems will face.

Both FBCEnergy and ADP have large estimate ranges due to the uncertainties in the underlying data, particularly the scenario inputs. This presents a problem when comparison between alternatives is conducted. It is likely that FBCEnergy and ADP estimates of different systems will have overlapping estimate ranges. Median values of the FBCEnergy estimate will provide a point value the system is most likely to experience. Decision makers can use the median value when comparing systems.

The estimates are also highly sensitive to scenario assumptions and the commodity cost of fuel. This is shown in the sensitivity analysis section and is shown in Figure 18. Fuel is the only input that has an effect on every element of the fuel delivery system and thus has a large effect on FBCEnergy results. Scenario assumptions, such as the use of TA-Os or aviation elements have a large effect on FBCEnergy results due to the high costs of these assets.

Fuel efficiency change on the AoA vehicle does not affect ADP. ADP is the price of fuel the AoA vehicle consumes and is dependent on the fuel delivery system. For this reason, the ADP for different combat systems with identical scenario assumptions will be the same. Therefore, decision makers in the acquisition process will have no ability to

affect ADP of the vehicle they are procuring, yet efficiencies of fuel delivery systems and escorts will affect the ADP of the AoA vehicle.

B. RECOMMENDATIONS

- We recommend FBCEnergy be used only to analyze distinctly different systems prior to Milestone A to avoid minimizing the impact of efficiency efforts.
- All FBCEnergy comparisons need consistent commodity cost of fuel and scenario assumptions to yield useful comparison. When different scenario assumptions are used, no useful comparison can be made.
- Median values from FBCEnergy estimates should be used as the measure of central tendency when comparing systems in the AoA to ensure the most likely cost is used for comparison.
- ADP should be viewed as a function of the fuel delivery system and not dependent on vehicle being procured.

C. AREAS OF FURTHER STUDY

- Expansion of our model to include simulation-based infrastructure costs. Accounting for the uncertainty in infrastructure costs is necessary due to the high impact of infrastructure cost on FBCEnergy.
- Expansion of the model to account for more scenario uncertainty. Creating uncertainty in the model will enable more scenario parameters to be analyzed with a single model. This may decrease the sensitivity of the analysis on scenario parameters. This may be accomplished similarly to the Probability of Use parameter in our model or by inclusion of additional Monte Carlo simulation engines.
- Expansion of the model to account for more complex scenarios. Currently escort aircraft can only be assigned to a ground convoy or air delivery section. For example, our model cannot calculate for escorting both ground and air in the same scenario.

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APPENDIX A. FINDINGS AND RECOMMENDATIONS FROM THE 2008 REPORT OF THE DEFENSE SCIENCE BOARD TASK FORCE ON DOD ENERGY STRATEGY

- *Finding 1*: The recommendations from the 2001 Defense Science Board Task Force Report "More Capable Warfighting Through Reduced Fuel Burden" have not been implemented.
- *Finding 2*: Critical national security and Homeland defense missions are at an unacceptably high risk of extended outage from failure of the grid.
- *Finding 3*: The Department lacks the strategy, policies, metrics, information, and governance structure necessary to properly manage its energy risks.
- *Finding 4*: There are technologies available now to make DoD systems more energy efficient, but they are undervalued, slowing their implementation and resulting in inadequate future S&T investments.
- *Finding 5*: There are many opportunities to reduce energy demand by changing wasteful operational practices and procedures.
- *Finding 6*: Operational risks from fuel disruption require demand-side remedies; mission risks from electricity disruption to installations require both demand- and supply-side remedies.

- *Recommendation 1*: Accelerate efforts to implement energy efficiency Key Performance Parameters (KPPs) and use the Fully Burdened Cost of Fuel (FBCF), to inform all acquisition trades and analyses about their energy consequences, as recommended by the 2001 Task Force.
- *Recommendation 2*: Reduce the risk to critical missions at fixed installations from loss of commercial power and other critical national infrastructure.
- *Recommendation 3*: Establish a Department-wide strategic plan that establishes measurable goals, achieves the business process changes recommended by the 2001 DSB report and establishes clear responsibility and accountability.
- *Recommendation 4:* Invest in energy efficient and alternative energy technologies to a level commensurate with their operational and financial value.
- *Recommendation 5*: Identify and exploit near-term opportunities to reduce energy use through policies and incentives that change operational procedures.

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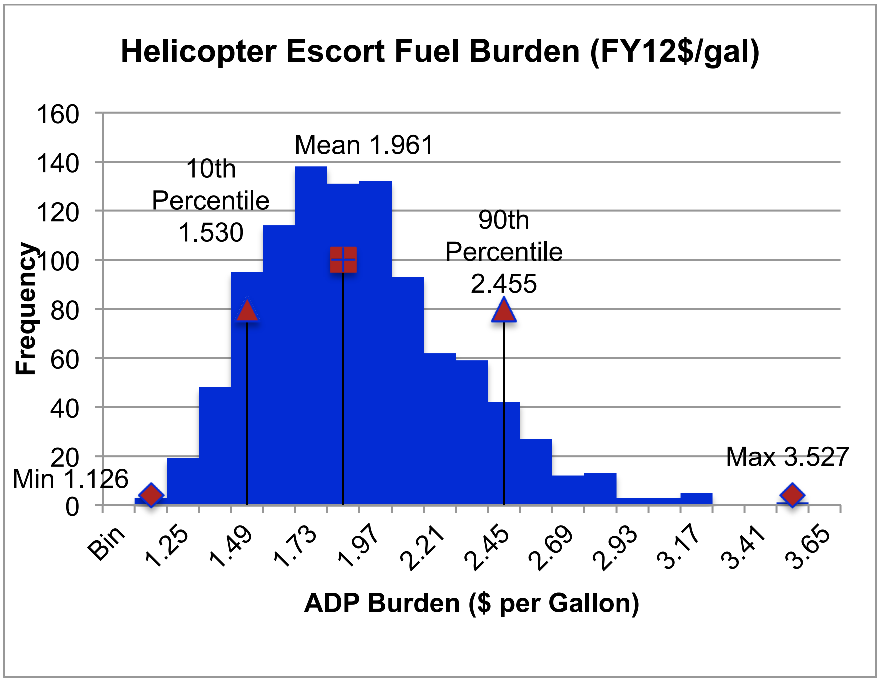
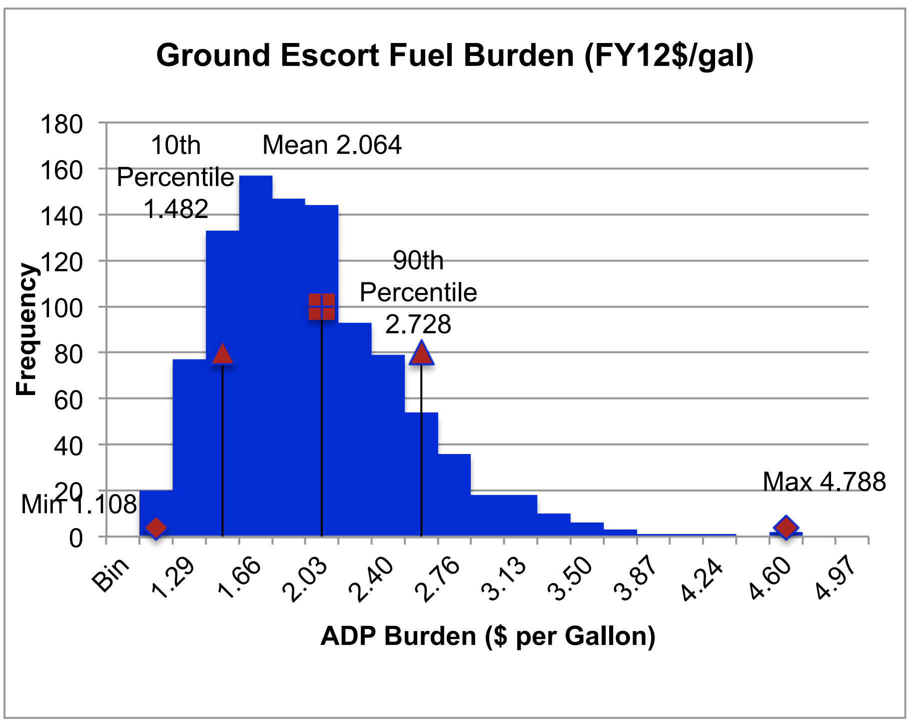
APPENDIX B. SCENARIO 1 INPUTS

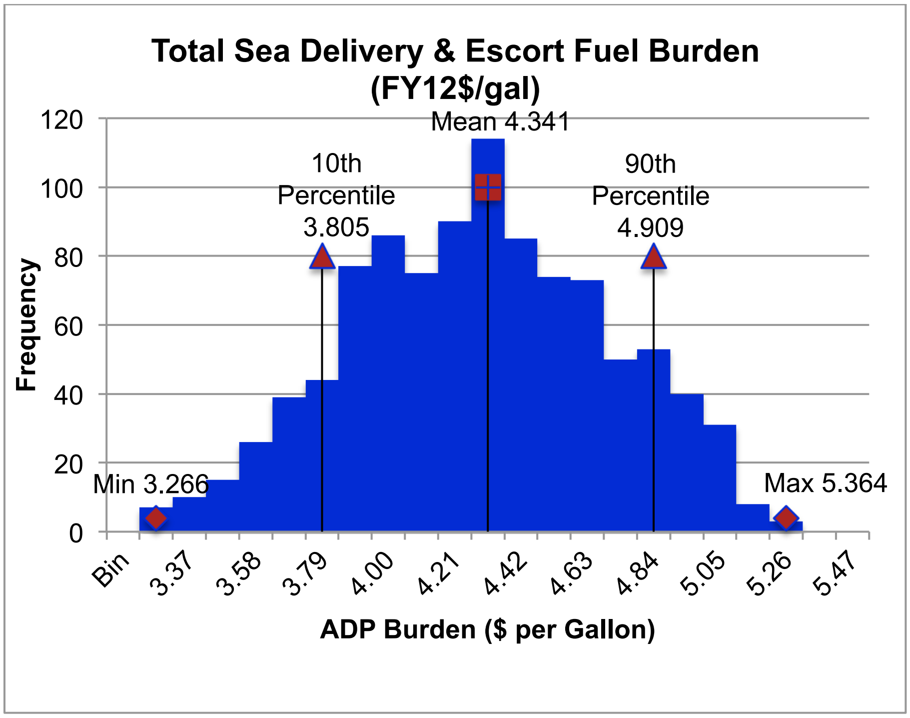
Route Specifics				
Fuel Supply Chain	Delivery	Escort		
Fuel Purchase				
Element 1	Sea	Sea		
Element 2	Land	Land		
Element 3	0	Chopper		
Element 4	0	0		
Fuel Burn				
Ground Convoy Route Length	(Statute Miles)			
Min	320			
Mode	407			
Max	581			
Std Dev	132.895			
Lognorm Param M	6.047			
Lognorm Param S	0.300			
Distribution Selection	Triangular			
Element 2: Fuel Delivery Assets				
Land Delivery Assets	MTVR Cargo	F-MTV	LVSR	
Probability of Use	0.34	0.33	0.33	
Asset Used (1=yes, 0=no)	1	1	1	
Probability of Loss	(% per year)			
Min	0.00125	0.00125	0.00125	
Mode	0.00015	0.00015	0.00015	
Max	0.00063	0.00063	0.00063	
Std Dev	0.001	0.001	0.001	
Lognorm Param M	-7.634	-7.634	-7.634	
Lognorm Param S	1.100	1.100	1.100	
Distribution Selection	Triangular	Triangular	Triangular	
Route Speed	(mph)			
Min	5.0	5.0	5.0	
Mode	10.0	10.0	10.0	
Max	15.0	15.0	15.0	
Std Dev	5.000	5.000	5.000	
Lognorm Param M	2.207	2.207	2.207	
Lognorm Param S	0.556	0.556	0.556	
Distribution Selection	Triangular	Triangular	Triangular	

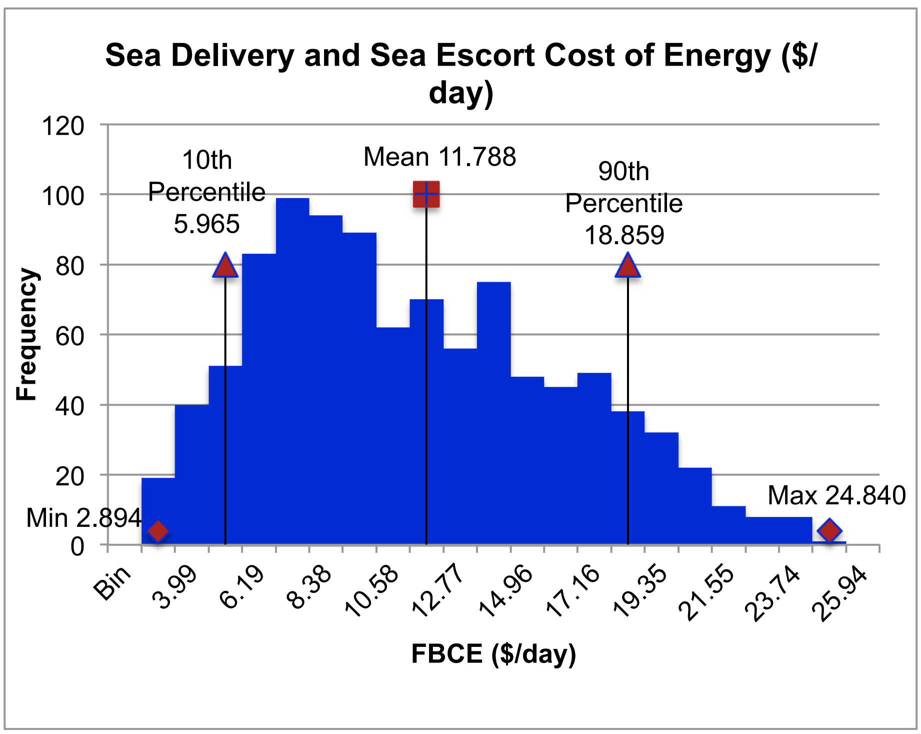
Element 3: Security				
Aviation Force Protection	H-1	F-35B		
Escort-to-Delivery Ratio	0.05	N/A		
Primary Escort Type	Ground (MVTR)	Rotor (CH53)		
Percentage of Route Escorted	0.5	N/A		
Probability of Loss	(% per year)			
Min	0.00009	N/A		
Mode	0.00010	N/A		
Max	0.00011	N/A		
Std Dev	0.000	N/A		
Lognorm Param M	-9.214	N/A		
Lognorm Param S	0.100	N/A		
Distribution Selection	Triangular	N/A		
Land Force Protection	MRAP	HMMWV	LAV-25	M-ATV
Probability of Use	0.25	0.25	0.25	0.25
Escort-to-Delivery Ratio	0.34	0.34	0.34	0.34
Probability of Loss	(% per year)			
Min	0.00125	0.00125	0.00125	0.00125
Mode	0.00015	0.00015	0.00015	0.00015
Max	0.00063	0.00063	0.00063	0.00063
Std Dev	0.001	0.001	0.001	0.001
Lognorm Param M	-7.634	-7.634	-7.634	-7.634
Lognorm Param S	1.100	1.100	1.100	1.100
Distribution Selection	Triangular	Triangular	Triangular	Triangular

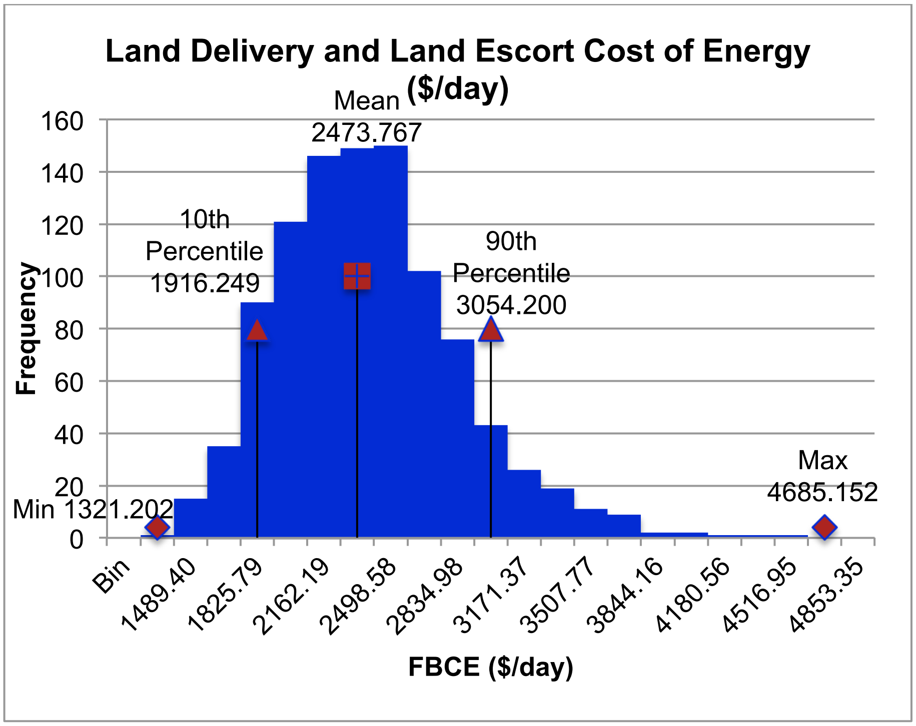
APPENDIX C. SCENARIO 1 OUTPUTS

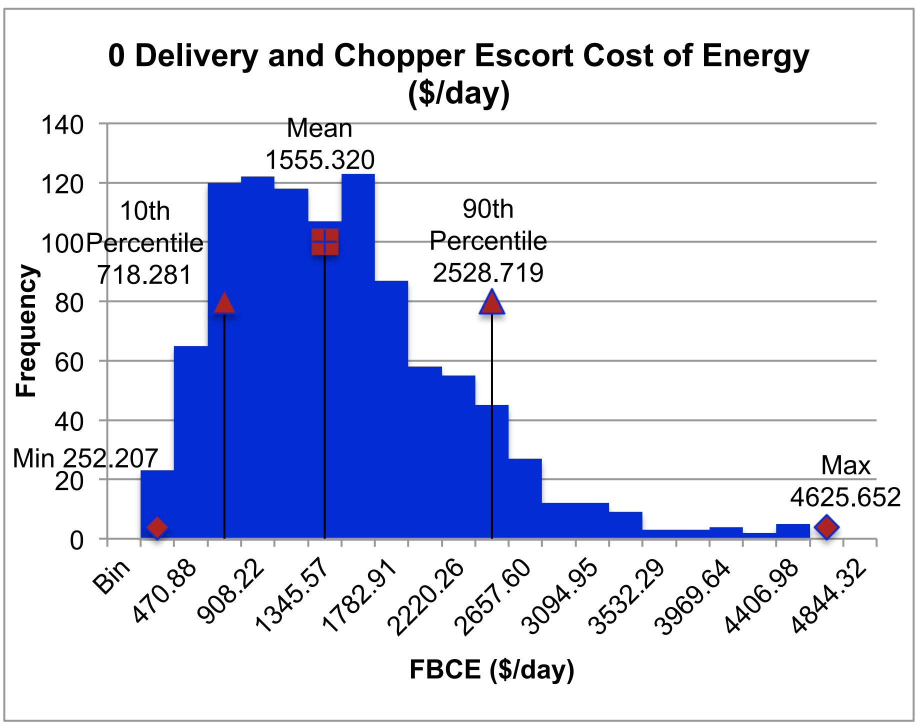


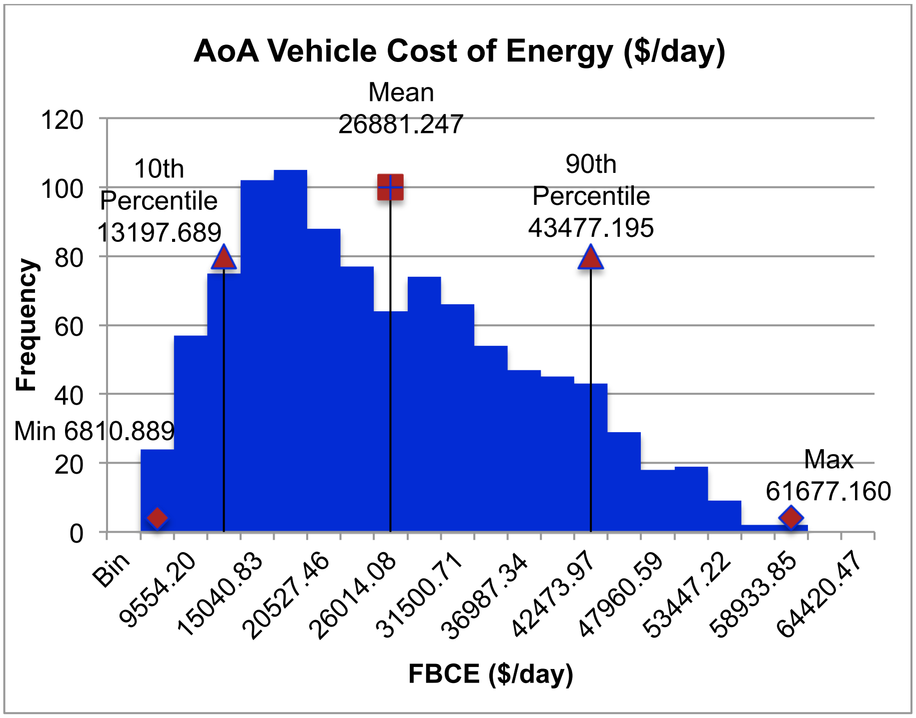


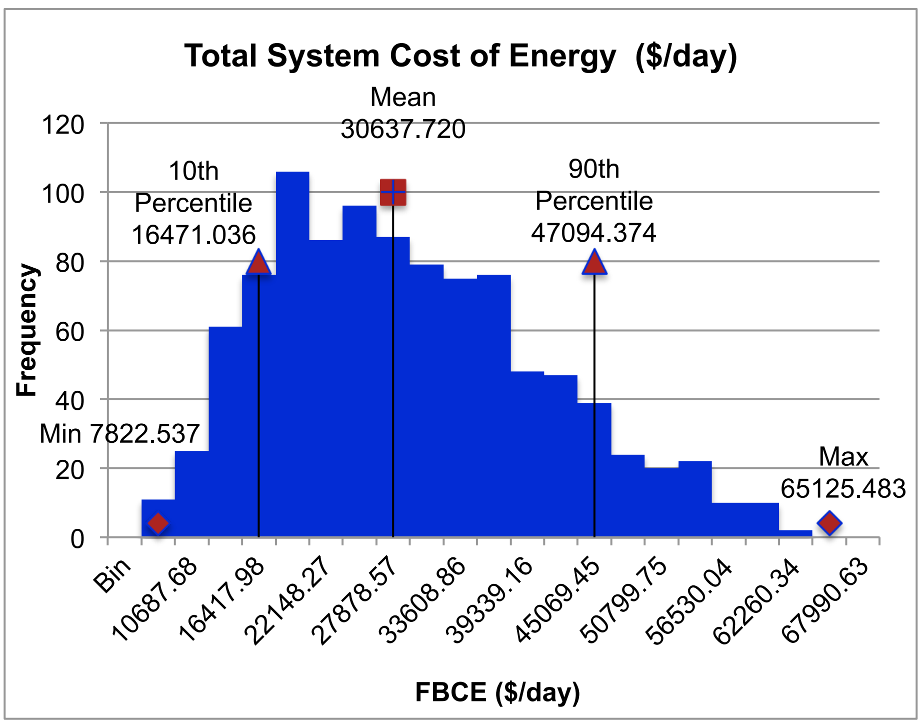

Total Sea Delivery & Escort Fuel Burden (FY12$/gal)
Mean 4.341
10th Percentile 3.805
90th Percentile 4.909
Min 3.266
Max 5.364
Frequency
120
100
80
60
40
20
0
Bin
3.37
3.58
3.79
4.00
4.21
4.42
4.63
4.84
5.05
5.26
5.47
ADP Burden ($ per Gallon)


Sea Delivery and Sea Escort Cost of Energy ($/day)
10th Percentile 5.965
Mean 11.788
90th Percentile 18.859
Min 2.894
Max 24.840
Frequency
120
100
80
60
40
20
0
Bin
3.99
6.19
8.38
10.58
12.77
14.96
17.16
19.35
21.55
23.74
25.94
FBCE ($/day)


Land Delivery and Land Escort Cost of Energy ($/day)
Mean 2473.767
10th Percentile 1916.249
90th Percentile 3054.200
Min 1321.202
Max 4685.152
Frequency
160
140
120
100
80
60
40
20
0
Bin
1489.40
1825.79
2162.19
2498.58
2834.98
3171.37
3507.77
3844.16
4180.56
4516.95
4853.35
FBCE ($/day)


0 Delivery and Chopper Escort Cost of Energy ($/day)
Mean 1555.320
10th Percentile 718.281
90th Percentile 2528.719
Min 252.207
Max 4625.652
Frequency
140
120
100
80
60
40
20
0
Bin
470.88
908.22
1345.57
1782.91
2220.26
2657.60
3094.95
3532.29
3969.64
4406.98
4844.32
FBCE ($/day)


AoA Vehicle Cost of Energy ($/day)
Mean
26881.247
10th
Percentile
13197.689
90th
Percentile
43477.195
Min 6810.889
Max
61677.160
Frequency
120
100
80
60
40
20
0
Bin
9554.20
15040.83
20527.46
26014.08
31500.71
36987.34
42473.97
47960.59
53447.22
58933.85
64420.47
FBCE ($/day)


Total System Cost of Energy ($/day)
Mean
30637.720
10th
Percentile
16471.036
90th
Percentile
47094.374
Min 7822.537
Max
65125.483
Frequency
120
100
80
60
40
20
0
Bin
10687.68
16417.98
22148.27
27878.57
33608.86
39339.16
45069.45
50799.75
56530.04
62260.34
67990.63
FBCE ($/day)

APPENDIX D. SCENARIO 2 INPUTS

Route Specifics				
Fuel Supply Chain	**Delivery**	**Escort**		
Fuel Purchase				
Element 1	Sea	Sea		
Element 2	CH53	Chopper		
Element 3	Land	Land		
Element 4	0	0		
Fuel Burn				
Helicopter Delivery Route Length (N miles)	CH-53E			
Min	15			
Mode	20			
Max	30			
Std Dev	7.638			
Lognorm Param M	3.035			
Lognorm Param S	0.348			
Distribution Selection	Triangular			
Ground Convoy Route Length	(Statute Miles)			
Min	320			
Mode	407			
Max	581			
Std Dev	132.895			
Lognorm Param M	6.047			
Lognorm Param S	0.300			
Distribution Selection	Triangular			
Element 2: Fuel Delivery Assets				
Air Delivery Assets	CH-53E	KC-130J		
Asset Used (1=yes, 0=no)	1	0		
Probability of Loss	(% per year)			
Min	0.00009	N/A		
Mode	0.00010	N/A		
Max	0.00011	N/A		
Std Dev	0.000	N/A		
Lognorm Param M	-9.214	N/A		
Lognorm Param S	0.100	N/A		
Distribution Selection	Triangular	N/A		
Flight Speed	knots			
Min	118.8000	N/A		

Mode	120.0000	N/A		
Max	121.2000	N/A		
Std Dev	1.200	N/A		
Lognorm Param M	4.787	N/A		
Lognorm Param S	0.010	N/A		
Distribution Selection	Triangular	N/A		
Land Delivery Assets	MTVR Cargo	F-MTV	LVSR	
Probability of Use	0.34	0.33	0.33	
Asset Used (1=yes, 0=no)	1	1	1	
Probability of Loss	(% per year)			
Min	0.00125	0.00125	0.00125	
Mode	0.00015	0.00015	0.00015	
Max	0.00063	0.00063	0.00063	
Std Dev	0.001	0.001	0.001	
Lognorm Param M	-7.634	-7.634	-7.634	
Lognorm Param S	1.100	1.100	1.100	
Distribution Selection	Triangular	Triangular	Triangular	
Route Speed	(mph)			
Min	5.0	5.0	5.0	
Mode	10.0	10.0	10.0	
Max	15.0	15.0	15.0	
Std Dev	5.000	5.000	5.000	
Lognorm Param M	2.207	2.207	2.207	
Lognorm Param S	0.556	0.556	0.556	
Distribution Selection	Triangular	Triangular	Triangular	
Element 3: Security				
Aviation Force Protection	H-1	F-35B		
Escort-to-Delivery Ratio	1	N/A		
Primary Escort Type	Rotor (CH53)	Rotor (CH53)		
Percentage of Route Escorted	1	N/A		
Probability of Loss	(% per year)			
Min	0.00009	N/A		
Mode	0.00010	N/A		
Max	0.00011	N/A		
Std Dev	0.000	N/A		
Lognorm Param M	-9.214	N/A		
Lognorm Param S	0.100	N/A		
Distribution Selection	Triangular	N/A		
Land Force Protection	MRAP	HMMWV	LAV-25	M-ATV
Probability of Use	0.25	0.25	0.25	0.25

Escort-to-Delivery Ratio	0.34	0.34	0.34	0.34
Probability of Loss	(% per year)			
Min	0.00125	0.00125	0.00125	0.00125
Mode	0.00015	0.00015	0.00015	0.00015
Max	0.00063	0.00063	0.00063	0.00063
Std Dev	0.001	0.001	0.001	0.001
Lognorm Param M	-7.634	-7.634	-7.634	-7.634
Lognorm Param S	1.100	1.100	1.100	1.100
Distribution Selection	Triangular	Triangular	Triangular	Triangular

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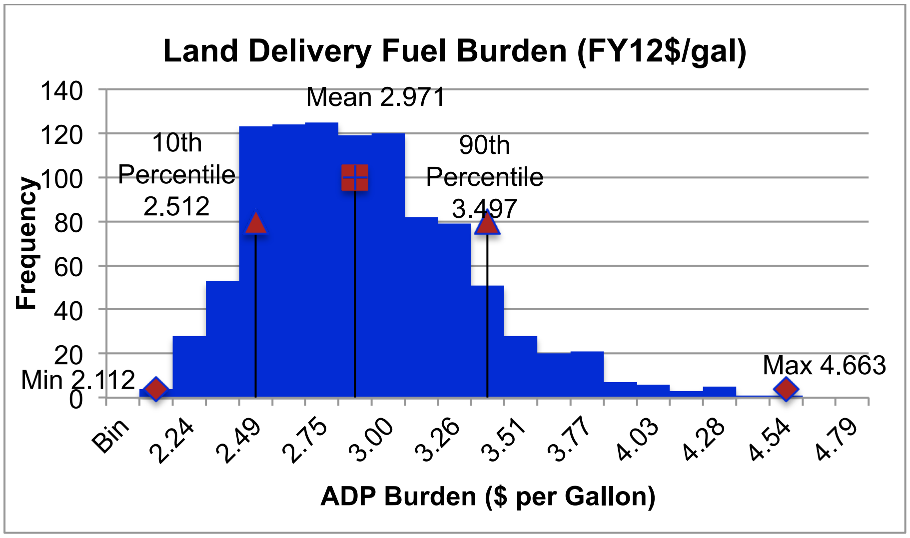
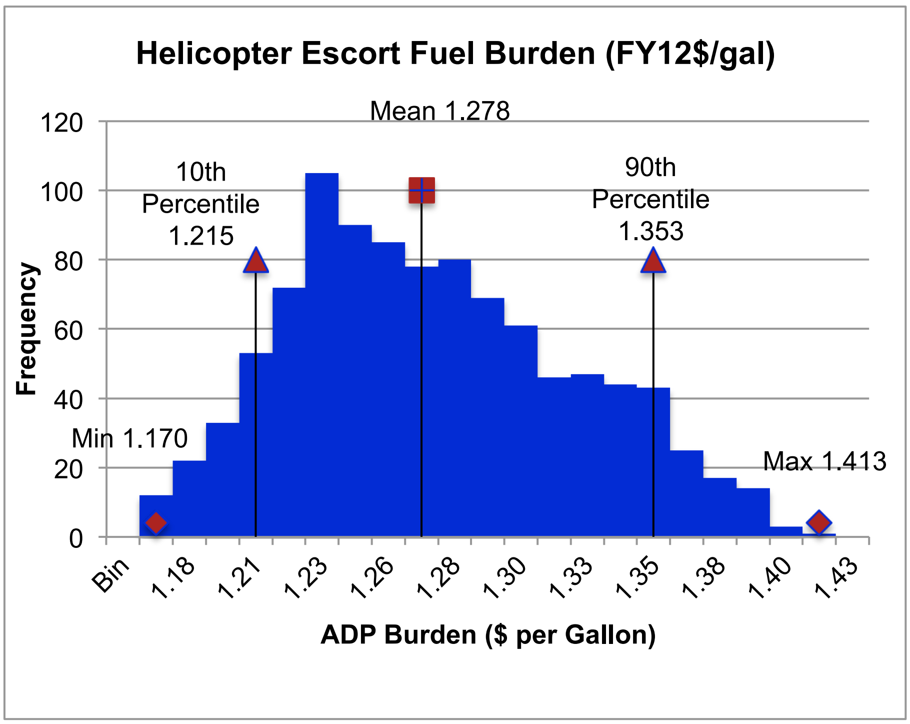
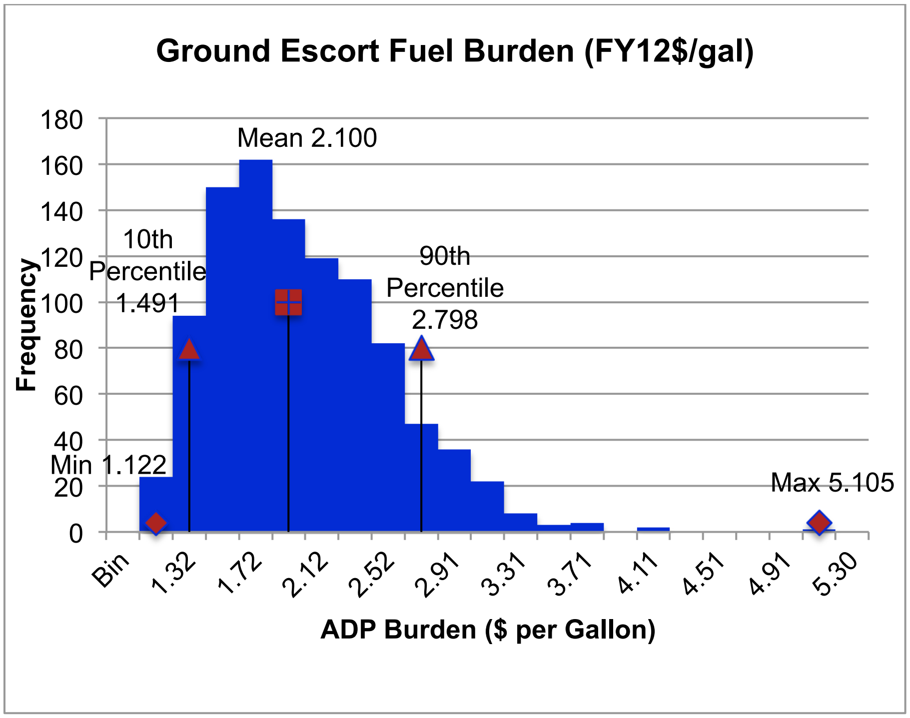
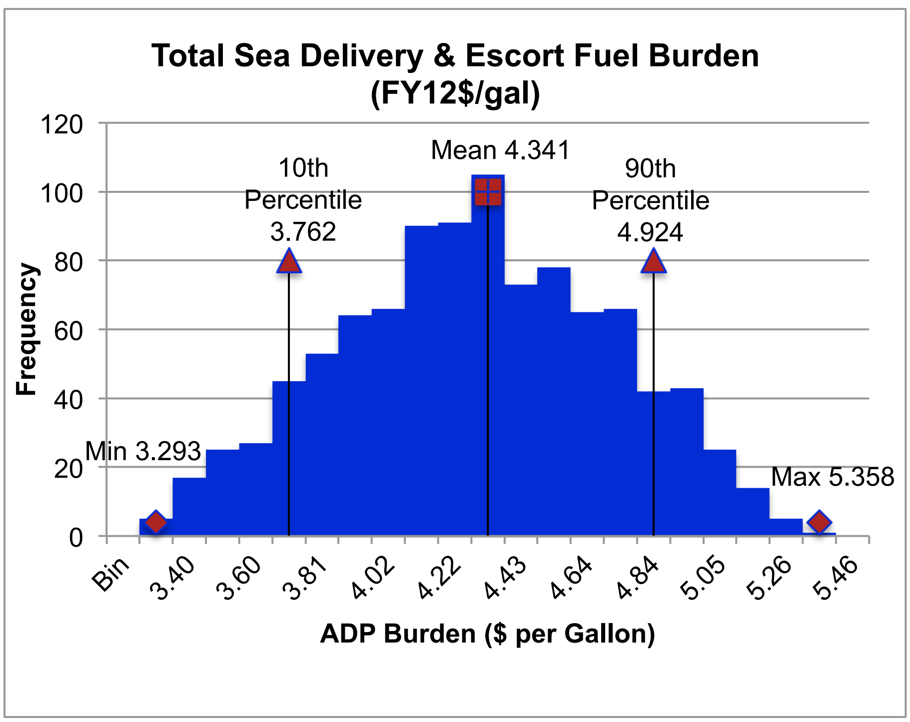
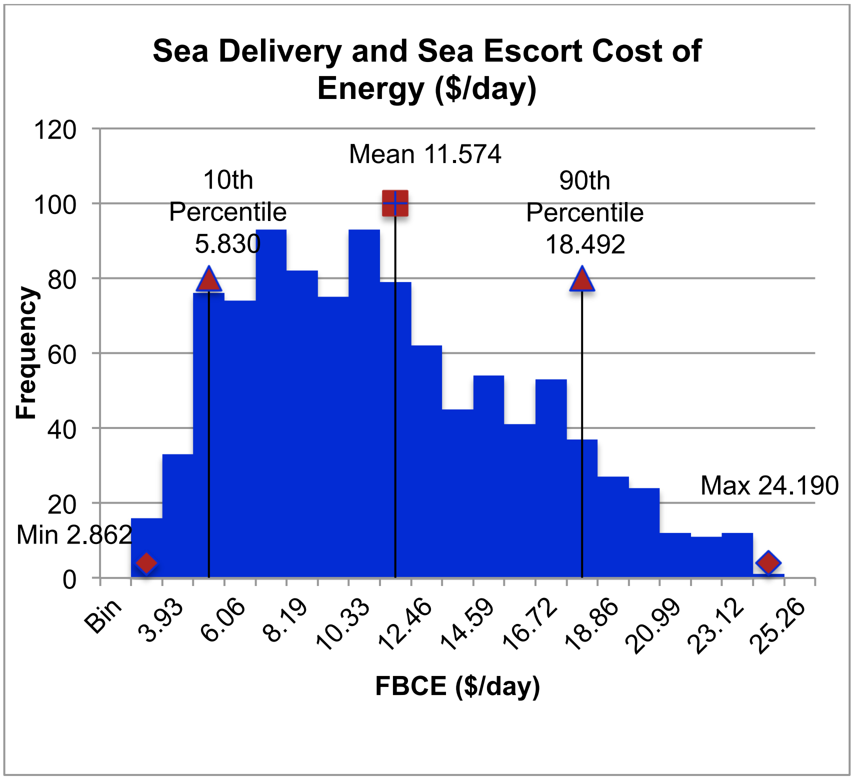
APPENDIX E. SCENARIO 2 OUTPUTS

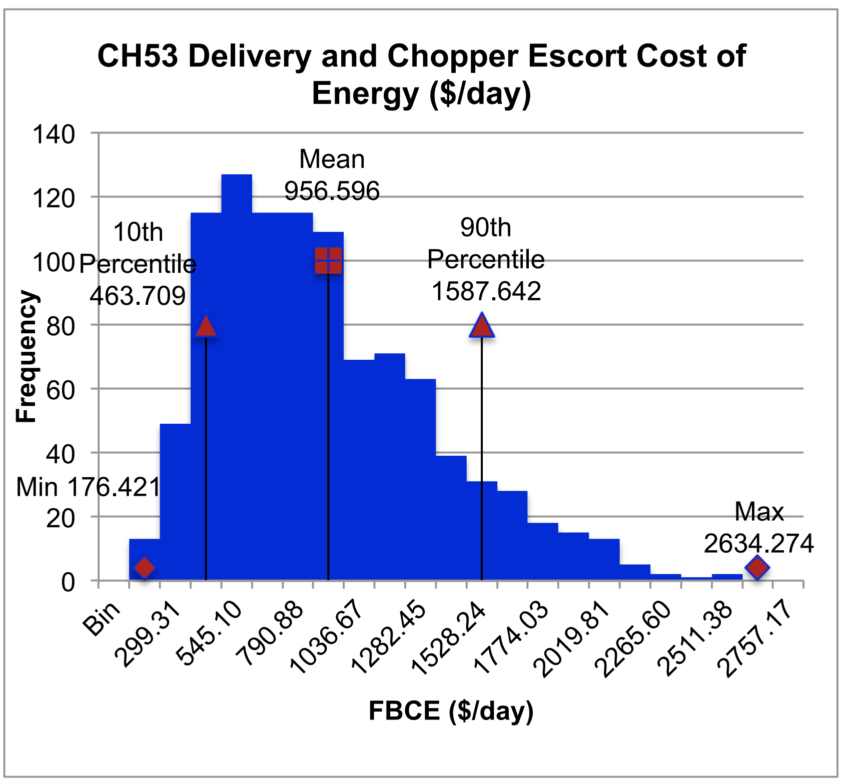


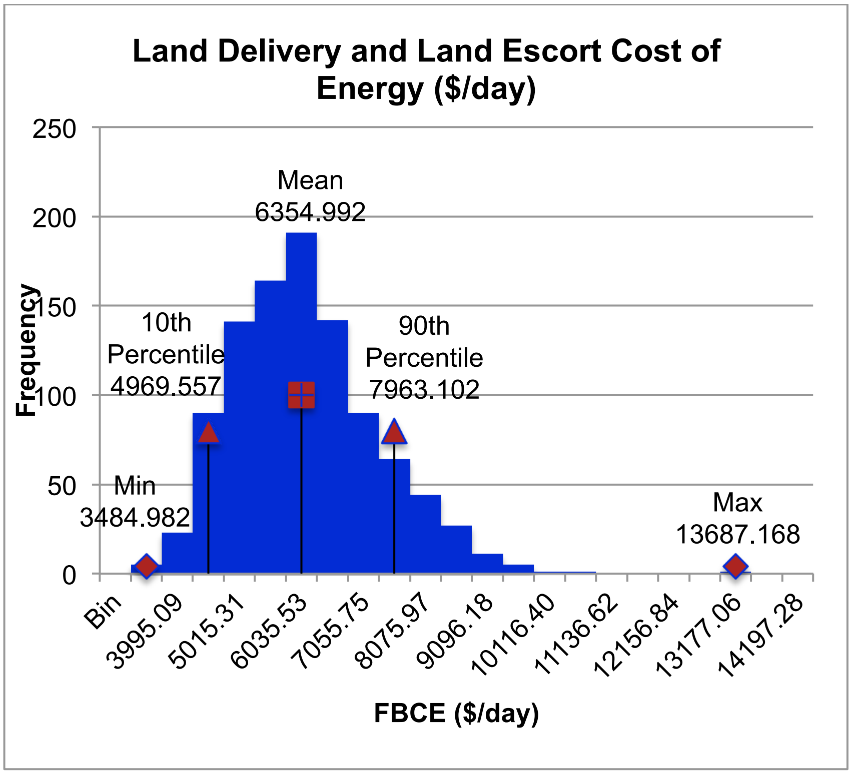


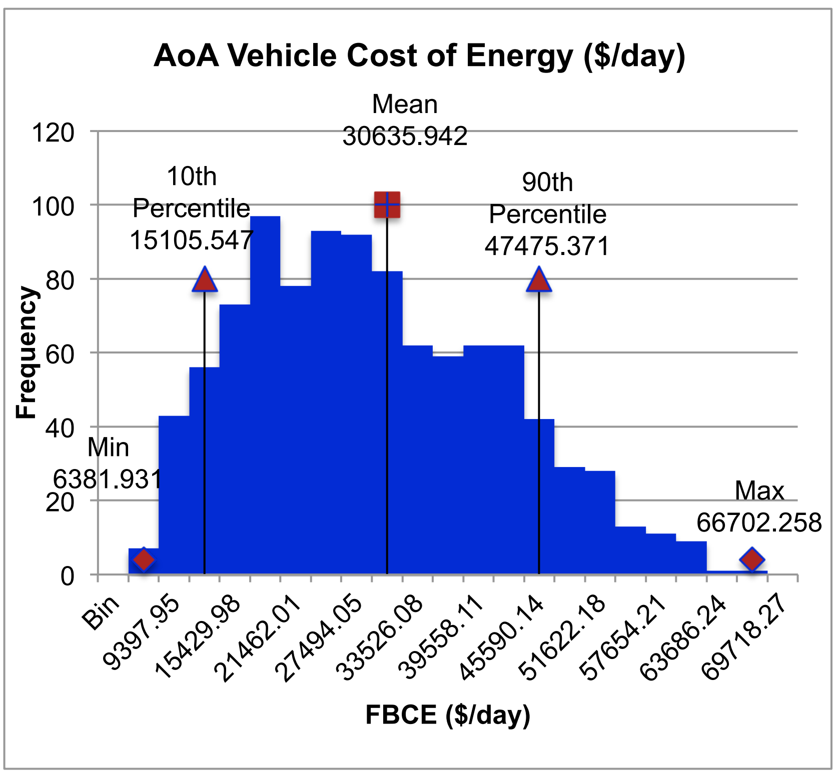

Ground Escort Fuel Burden (FY12$/gal)
Frequency
180
160
140
120
100
80
60
40
20
0
Mean 2.100
10th
Percentile
1.491
90th
Percentile
2.798
Min 1.122
Max 5.105
Bin
1.32
1.72
2.12
2.52
2.91
3.31
3.71
4.11
4.51
4.91
5.30
ADP Burden ($ per Gallon)

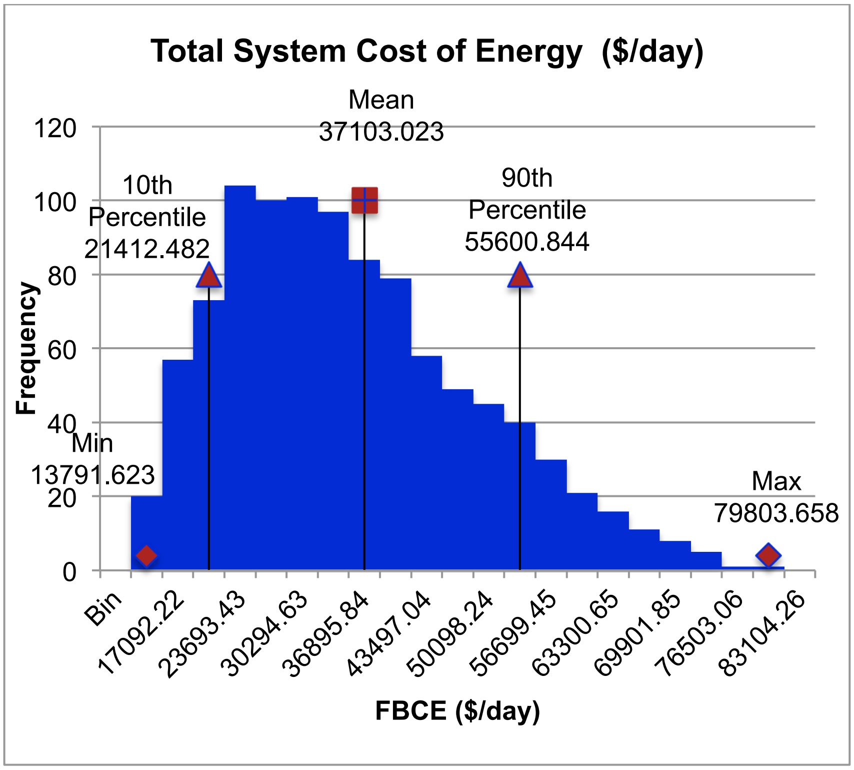

Total Sea Delivery & Escort Fuel Burden
(FY12$/gal)
Frequency
120
100
80
60
40
20
0
Mean 4.341
10th
Percentile
3.762
90th
Percentile
4.924
Min 3.293
Max 5.358
Bin
3.40
3.60
3.81
4.02
4.22
4.43
4.64
4.84
5.05
5.26
5.46
ADP Burden ($ per Gallon)


Sea Delivery and Sea Escort Cost of Energy ($/day)
Frequency
120
100
80
60
40
20
0
Mean 11.574
10th Percentile 5.830
90th Percentile 18.492
Max 24.190
Min 2.862
Bin
3.93
6.06
8.19
10.33
12.46
14.59
16.72
18.86
20.99
23.12
25.26
FBCE ($/day)


CH53 Delivery and Chopper Escort Cost of Energy ($/day)
Frequency
140
120
100
80
60
40
20
0
Mean 956.596
10th Percentile 463.709
90th Percentile 1587.642
Min 176.421
Max 2634.274
Bin
299.31
545.10
790.88
1036.67
1282.45
1528.24
1774.03
2019.81
2265.60
2511.38
2757.17
FBCE ($/day)


Land Delivery and Land Escort Cost of Energy ($/day)
Frequency
250
200
150
100
50
0
Mean
6354.992
10th
Percentile
4969.557
90th
Percentile
7963.102
Min
3484.982
Max
13687.168
Bin
3995.09
5015.31
6035.53
7055.75
8075.97
9096.18
10116.40
11136.62
12156.84
13177.06
14197.28
FBCE ($/day)


AoA Vehicle Cost of Energy ($/day)
Frequency
120
100
80
60
40
20
0
Mean
30635.942
10th
Percentile
15105.547
90th
Percentile
47475.371
Min
6381.931
Max
66702.258
Bin
9397.95
15429.98
21462.01
27494.05
33526.08
39558.11
45590.14
51622.18
57654.21
63686.24
69718.27
FBCE ($/day)



Total System Cost of Energy ($/day)
Mean
37103.023
10th
Percentile
21412.482
90th
Percentile
55600.844
Min
13791.623
Max
79803.658
Frequency
120
100
80
60
40
20
0
Bin
17092.22
23693.43
30294.63
36895.84
43497.04
50098.24
56699.45
63300.65
69901.85
76503.06
83104.26
FBCE ($/day)

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APPENDIX F. SCENARIO 3 INPUTS

Route Specifics				
Fuel Supply Chain	**Delivery**	**Escort**		
Fuel Purchase				
Element 1	Fixed Wing	Fixed Wing		
Element 2	Land	Land		
Element 3	0	0		
Element 4	0	0		
Fuel Burn				
Fixed Wing Delivery Route Length	KC-130J			
Min	415			
Mode	735			
Max	996			
Std Dev	290.999			
Lognorm Param M	6.511			
Lognorm Param S	0.445			
Distribution Selection	Triangular			
Ground Convoy Route Length	(Statute Miles)			
Min	320			
Mode	407			
Max	581			
Std Dev	132.895			
Lognorm Param M	6.047			
Lognorm Param S	0.300			
Distribution Selection	Triangular			
Element 2: Fuel Delivery Assets				
Air Delivery Assets	CH-53E	KC-130J		
Asset Used (1=yes, 0=no)	0	1		
Probability of Loss	(% per year)			
Min	N/A	0.90090		
Mode	N/A	1.00100		
Max	N/A	1.10110		
Std Dev	N/A	0.100		
Lognorm Param M	N/A	-0.002		
Lognorm Param S	N/A	0.100		
Distribution Selection	N/A	Triangular		

Flight Speed	knots			
Min	118.8000	237.6000		
Mode	120.0000	240.0000		
Max	121.2000	242.0000		
Std Dev	1.200	2.203		
Lognorm Param M	4.787	5.480		
Lognorm Param S	0.010	0.009		
Distribution Selection	Triangular	Triangular		
Land Delivery Assets	MTVR Cargo	F-MTV	LVSR	
Probability of Use	0.34	0.33	0.33	
Asset Used (1=yes, 0=no)	1	1	1	
Probability of Loss	(% per year)			
Min	0.00125	0.00125	0.00125	
Mode	0.00015	0.00015	0.00015	
Max	0.00063	0.00063	0.00063	
Std Dev	0.001	0.001	0.001	
Lognorm Param M	-7.634	-7.634	-7.634	
Lognorm Param S	1.100	1.100	1.100	
Distribution Selection	Triangular	Triangular	Triangular	
Route Speed	(mph)			
Min	5.0	5.0	5.0	
Mode	10.0	10.0	10.0	
Max	15.0	15.0	15.0	
Std Dev	5.000	5.000	5.000	
Lognorm Param M	2.207	2.207	2.207	
Lognorm Param S	0.556	0.556	0.556	
Distribution Selection	Triangular	Triangular	Triangular	
Element 3: Security				
Aviation Force Protection	H-1	F-35B		
Escort-to-Delivery Ratio	0	1		
Primary Escort Type	Rotor (CH53)	Fixed Wing (C130)		
Percentage of Route Escorted	0	0.41		
Probability of Loss	(% per year)			
Min	N/A	0.00009		
Mode	N/A	0.00010		
Max	N/A	0.00011		
Std Dev	N/A	0.000		
Lognorm Param M	N/A	-9.214		

Lognorm Param S	N/A	0.100		
Distribution Selection	N/A	Triangular		
Land Force Protection	MRAP	HMMWV	LAV-25	M-ATV
Probability of Use	0.25	0.25	0.25	0.25
Escort-to-Delivery Ratio	0.34	0.34	0.34	0.34
Probability of Loss	(% per year)			
Min	0.00125	0.00125	0.00125	0.00125
Mode	0.00015	0.00015	0.00015	0.00015
Max	0.00063	0.00063	0.00063	0.00063
Std Dev	0.001	0.001	0.001	0.001
Lognorm Param M	-7.634	-7.634	-7.634	-7.634
Lognorm Param S	1.100	1.100	1.100	1.100
Distribution Selection	Triangular	Triangular	Triangular	Triangular

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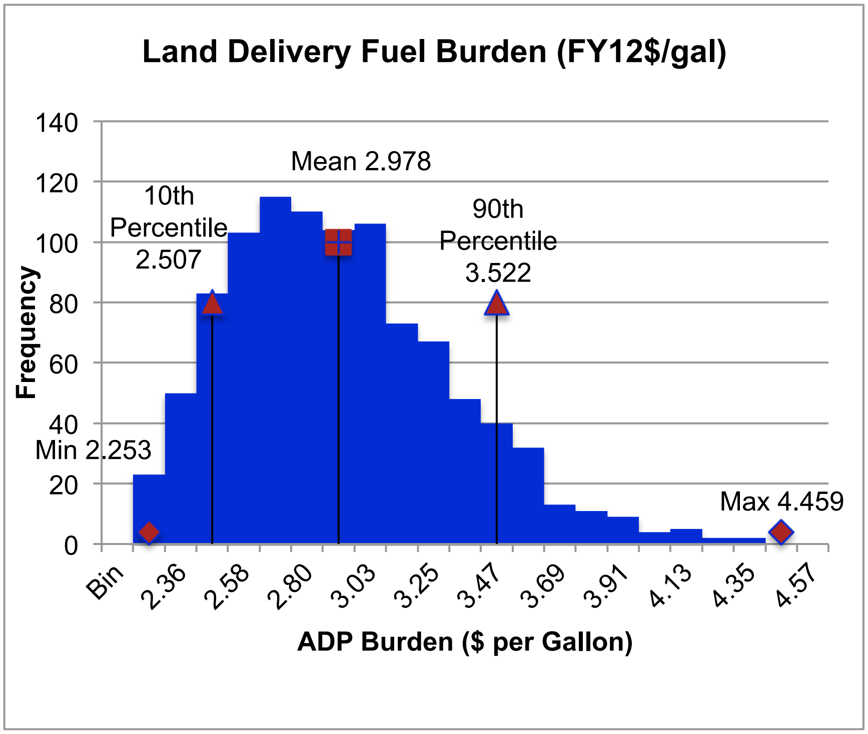
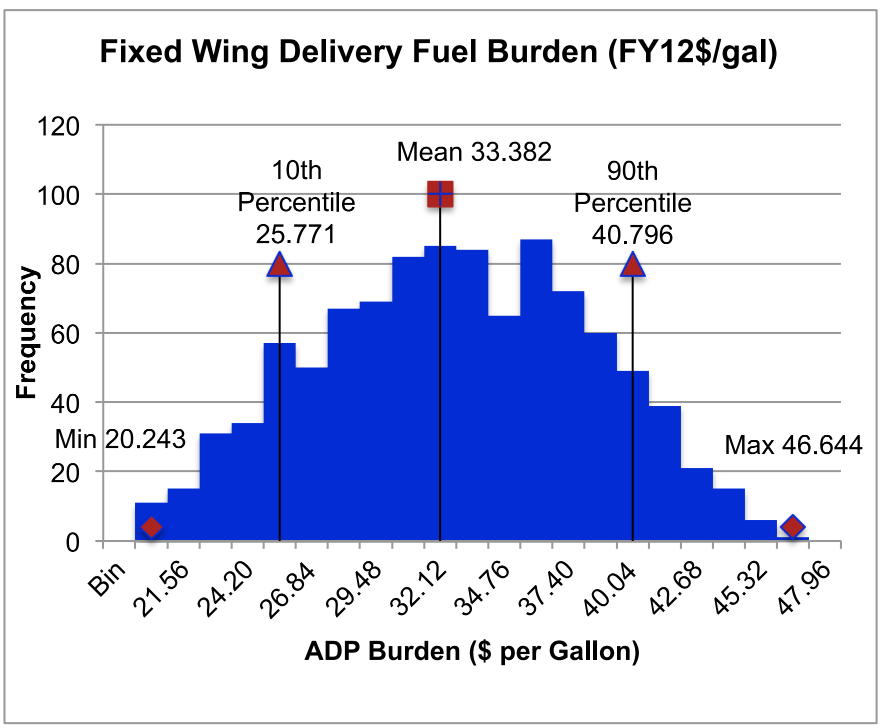
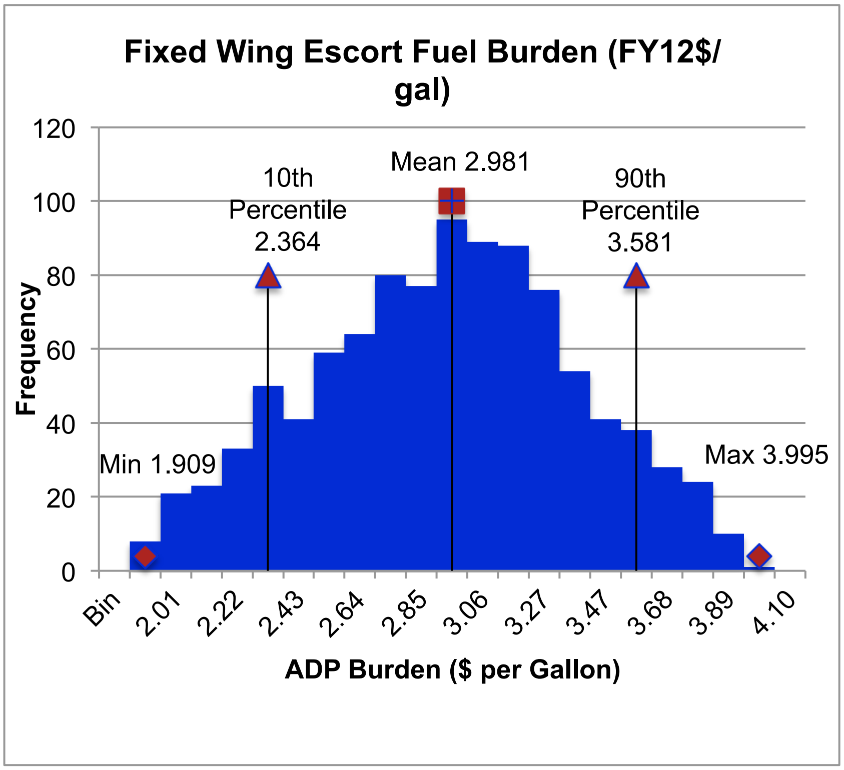
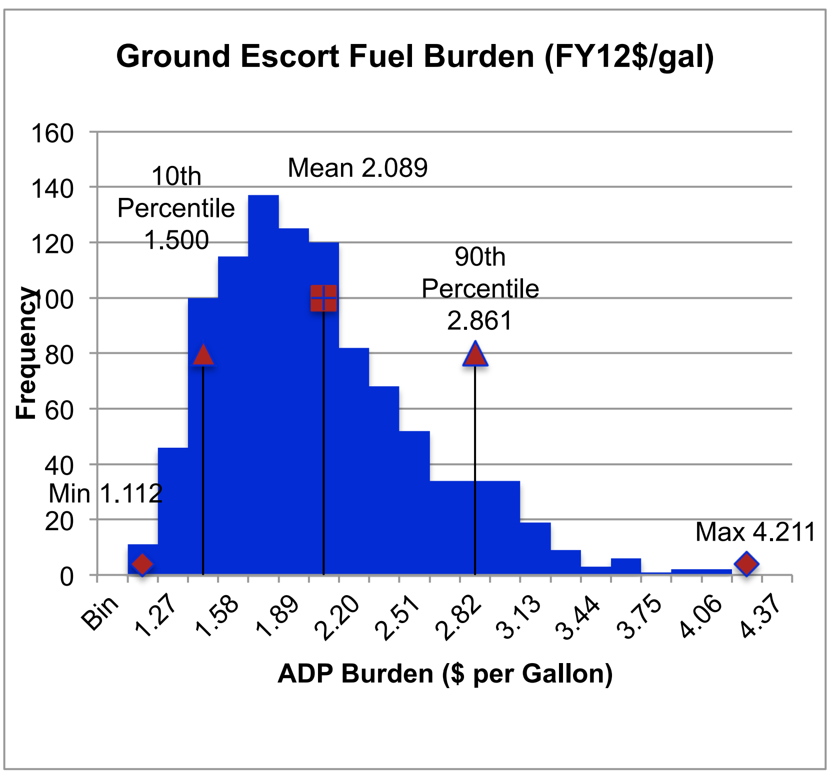
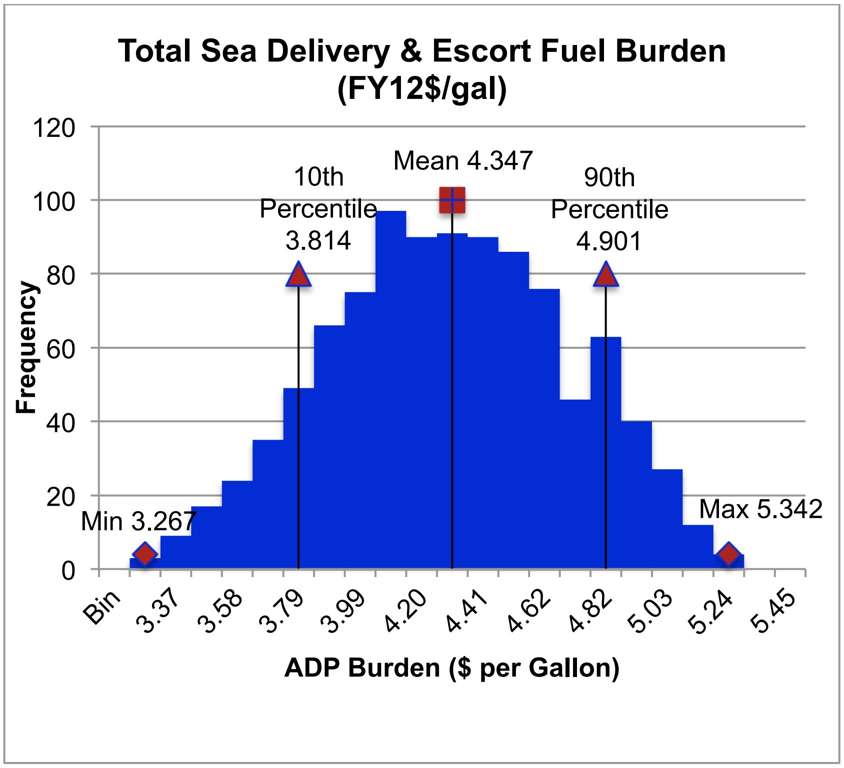
APPENDIX G. SCENARIO 3 OUTPUTS

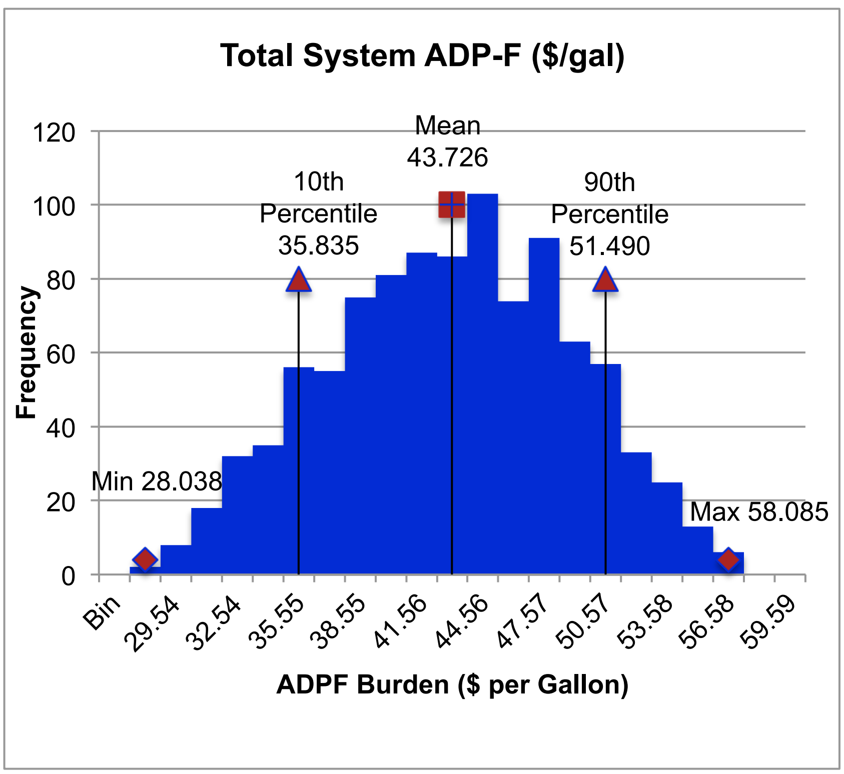


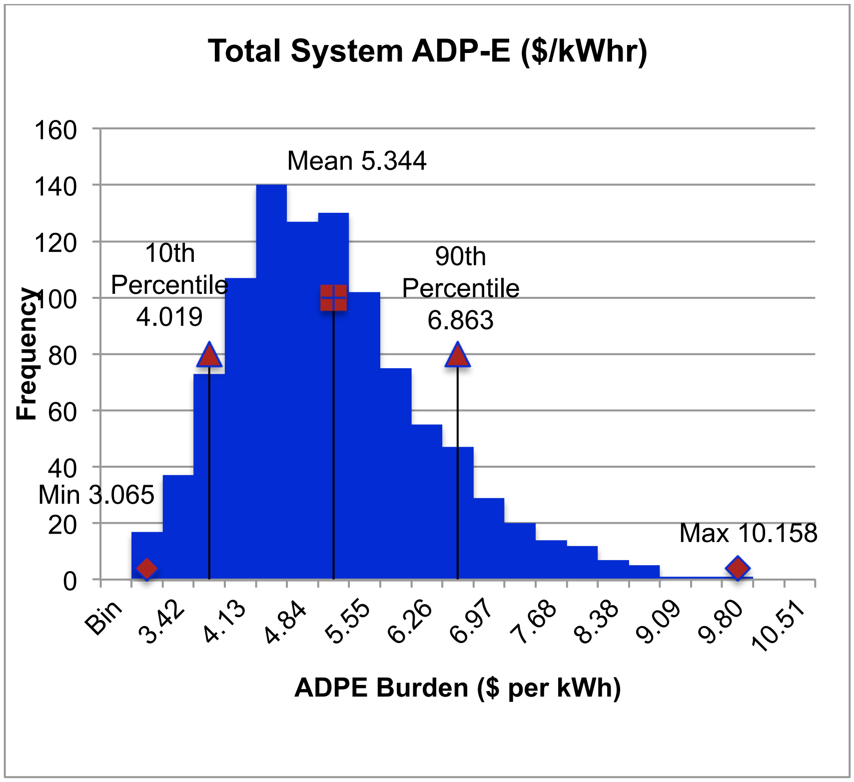



Fixed Wing Escort Fuel Burden (FY12$/gal)
Frequency
120
100
80
60
40
20
0
10th Percentile 2.364
Mean 2.981
90th Percentile 3.581
Min 1.909
Max 3.995
Bin
2.01
2.22
2.43
2.64
2.85
3.06
3.27
3.47
3.68
3.89
4.10
ADP Burden ($ per Gallon)


Ground Escort Fuel Burden (FY12$/gal)
Frequency
160
140
120
100
80
60
40
20
0
10th Percentile 1.500
Mean 2.089
90th Percentile 2.861
Min 1.112
Max 4.211
Bin
1.27
1.58
1.89
2.20
2.51
2.82
3.13
3.44
3.75
4.06
4.37
ADP Burden ($ per Gallon)


Total Sea Delivery & Escort Fuel Burden (FY12$/gal)
Frequency
120
100
80
60
40
20
0
Mean 4.347
10th Percentile 3.814
90th Percentile 4.901
Min 3.267
Max 5.342
Bin
3.37
3.58
3.79
3.99
4.20
4.41
4.62
4.82
5.03
5.24
5.45
ADP Burden ($ per Gallon)


Total System ADP-F ($/gal)
Frequency
120
100
80
60
40
20
0
Mean 43.726
10th Percentile 35.835
90th Percentile 51.490
Min 28.038
Max 58.085
Bin
29.54
32.54
35.55
38.55
41.56
44.56
47.57
50.57
53.58
56.58
59.59
ADPF Burden ($ per Gallon)



Total System ADP-E ($/kWhr)
160
140
120
100
80
60
40
20
0
Frequency
Mean 5.344
10th
Percentile
4.019
90th
Percentile
6.863
Min 3.065
Max 10.158
Bin
3.42
4.13
4.84
5.55
6.26
6.97
7.68
8.38
9.09
9.80
10.51
ADPE Burden ($ per kWh)

APPENDIX H. COST FACTOR NOTATION

$F_{O\&S,H,D}$	Delivery Helicopter O&S Cost Factor
$F_{Depr,H,D}$	Delivery Helicopter Depreciation Cost Factor
$F_{Loss,H,D}$	Delivery Helicopter Loss Cost Factor
$F_{DirI,H,D}$	Delivery Helicopter Direct Infrastructure Cost Factor
$F_{IndI,H,D}$	Delivery Helicopter Indirect Infrastructure Cost Factor
$F_{Envi,H,D}$	Delivery Helicopter Environmental Cost Factor
$F_{O\&S,FW,D}$	Delivery Fixed Wing O&S Cost Factor
$F_{Depr,FW,D}$	Delivery Fixed Wing Depreciation Cost Factor
$F_{Loss,FW,D}$	Delivery Fixed Wing Loss Cost Factor
$F_{DirI,FW,D}$	Delivery Fixed Wing Direct Infrastructure Cost Factor
$F_{IndI,FW,D}$	Delivery Fixed Wing Indirect Infrastructure Cost Factor
$F_{Envi,FW,D}$	Delivery Fixed Wing Environmental Cost Factor
$F_{O\&S,L,D_i}$	Delivery Land Vehicle O&S Cost Factor
F_{Depr,L,D_i}	Delivery Land Vehicle Depreciation Cost Factor
F_{Loss,L,D_i}	Delivery Land Vehicle Loss Cost Factor
F_{DirI,L,D_i}	Delivery Land Vehicle Direct Infrastructure Cost Factor
F_{IndI,L,D_i}	Delivery Land Vehicle Indirect Infrastructure Cost Factor
F_{Envi,L,D_i}	Delivery Land Vehicle Environmental Cost Factor
$F_{O\&S,S}$	Total Sea O&S Cost Factor
$F_{Depr,S}$	Total Sea Depreciation Cost Factor
$F_{Loss,S}$	Total Sea Loss Cost Factor
$F_{DirI,S}$	Total Sea Direct Infrastructure Cost Factor
$F_{IndI,S}$	Total Sea Indirect Infrastructure Cost Factor
$F_{Envi,S}$	Total Sea Environmental Cost Factor
$F_{O\&S,H,E}$	Escort Helicopter O&S Cost Factor
$F_{Depr,H,E}$	Escort Helicopter Depreciation Cost Factor
$F_{Loss,H,E}$	Escort Helicopter Loss Cost Factor
$F_{DirI,H,E}$	Escort Helicopter Direct Infrastructure Cost Factor
$F_{IndI,H,E}$	Escort Helicopter Indirect Infrastructure Cost Factor
$F_{Envi,H,E}$	Escort Helicopter Environmental Cost Factor
$F_{O\&S,FW,E}$	Escort Helicopter O&S Cost Factor
$F_{Depr,FW,E}$	Escort Helicopter Depreciation Cost Factor
$F_{Loss,FW,E}$	Escort Helicopter Loss Cost Factor
$F_{DirI,FW,E}$	Escort Helicopter Direct Infrastructure Cost Factor
$F_{IndI,FW,E}$	Escort Helicopter Indirect Infrastructure Cost Factor
$F_{Envi,FW,E}$	Escort Helicopter Environmental Cost Factor
$F_{O\&S,L,E_i}$	Escort Land Vehicle O&S Cost Factor
F_{Depr,L,E_i}	Escort Land Vehicle Depreciation Cost Factor
F_{Loss,L,E_i}	Escort Land Vehicle Loss Cost Factor

F_{DirI,L,E_i}	Escort Land Vehicle Direct Infrastructure Cost Factor
F_{IndI,L,E_i}	Escort Land Vehicle Indirect Infrastructure Cost Factor
F_{Envi,L,E_i}	Escort Land Vehicle Environmental Cost Factor

APPENDIX I. MONTE CARLO SIMULATION

A. TRIANGULAR DISTRIBUTION

Triangular distributions are used when data are limited. Triangular distributions are continuous probability distributions with lower limit *a*, upper limit *b* and mode *c*, where $a < b$ and $a \le c \le b$. (Hesse, 2000) The Triangular Inverse Transformation equation, used for generating triangular distributions, is shown in Equation 1:

$$\mathcal{T}^{-1}(a,b) = \begin{cases} a + \sqrt{RAND(b-a)(c-a)} & for\ RAND \le\ c-a \\ b - \sqrt{(1-RAND)(b-a)(b-c)} & for\ RAND > c-a \end{cases}. \tag{1}$$

B. UNIFORM DISTRIBUTION

The uniform or rectangular distribution is a family of probability distributions such that for each member of the family, all intervals of the same length on the distribution's support are equally probable. The support is defined by the two parameters, *a* and *b*, which are its minimum and maximum values. It is the maximum entropy probability distribution for a random variable *X* under no constraint other than that it is contained in the distribution's support. (Park & Bera, 2009) The Uniform Inverse Transform formula, used for generating uniform distributions, is shown in Equation 2:

$$\mathcal{U}^{-1}(a,b) = RAND(b-a) + a \tag{2}$$

where *a* is the minimum, *b* is the maximum, and RAND is a pseudorandom number.

C. NORMAL DISTRIBUTION

In normal distributions, the parameter μ is the mean or expectation and σ^2 is the variance. σ is known as the standard deviation. The distribution with $\mu = 0$ and $\sigma^2 = 1$ is called the standard normal distribution or the unit normal distribution. A normal distribution is often used as a first approximation to describe real-valued random variables that cluster around a single mean value. Normal distribution arises from the central limit theorem, which states that under mild conditions, the mean of a large number of random variables drawn from the same distribution is distributed approximately normally, irrespective of the form of the original distribution. (Casella &

Berger, 2001) Normal distributions are generated using the built-in "NORMINV" function in Microsoft Excel. Negative returns are truncated to zero.

D. LOGNORMAL DISTRIBUTION

Lognormal distribution is a continuous probability distribution of a random variable whose logarithm is normally distributed. If *X* is a random variable with a normal distribution, then *Y* = exp(*X*) has a log-normal distribution; likewise, if *Y* is log-normally distributed, then *X* = log(*Y*) has a normal distribution. The log-normal distribution is the distribution of a random variable that takes only positive real values. (Johnson, Kotz, & Balakrishnan, 1994) Log-normal distributions are generated using the built-in "LOGNORM.INV" function in Microsoft Excel.

The LOGNORM.INV function requires the mean and standard deviation of the natural log of the data. In this thesis, the mean of the natural log of the data is referred to as lognormal parameter M and the standard deviation of the natural log of the data is referred to as lognormal parameter S. We are unaware of any previous work that calculates these parameters directly from the underlying data without first taking the logarithm of each underlying data point.

Lognormal parameter M is derived from Equation 3, the algebraic mean:

$$\mu = \frac{\sum_{i=1}^{n} x_i}{n}. \tag{3}$$

Taking the natural log and applying the logarithmic identity for products results in Equation 4.

$$M = \frac{ln \prod_{i=1}^{n} x_i}{n} \quad , \tag{4}$$

where x_i is the data set and n is the number of observations.

Lognormal parameter S is derived in a similar manner. From the Equation 5, standard deviation:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \mu)^2}{n-1}}, \tag{5}$$

factoring the squared term yields

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} x_i{}^2 - n\mu^2}{n-1}}.$$

Taking the natural log and substituting the algebraic equation for the mean yields the following equation:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(lnx_i)^2 - n\left(\frac{\sum_{i=1}^{n} x_i}{n}\right)^2}{n-1}}.$$

Applying the logarithmic identity for products and algebraic manipulation yields Equation 6, Lognormal Parameter S.

$$S = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(lnx_i)^2 - \frac{(ln\prod_{i=1}^{n} x_i)^2}{n}}. \tag{6}$$

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BIBLIOGRAPHY

Armored Humvee [Image]. (n.d.). Retrieved from http://www.truckinweb.com/features/0910tr_united_states_marine_corps/photo_14.html

The Army Senior Energy Council and the Office of the Deputy Assistant Secretary of the Army for Energy and Partnerships. (2009). *Army energy security implementation strategy*. Washington, DC: Government Printing Office.

Bell Helicopter. (n.d.). *The Bell AH-1Z Zulu* [Image]. Retrieved from http://www.bellhelicopter.com/Military/AH-1Z/1291148375494.html#/?tab=highlights-tab

Casella, G., & Berger, R. L. (2001). *Statistical inference*. Pacific Grove, CA: Duxbury Press.

Center for Naval Analyses. (2009). *Powering America's defense: Energy and the risks to national security*. Alexandria, VA:Author.

Chairman of the Joint Chiefs of Staff. (2003). *Joint bulk petroleum and water doctrine* (Joint Publication 4–03). Retrieved from http://www.dtic.mil/doctrine/new_pubs/jp4_03.pdf

Chiang, A. C. (1984). *Fundamental methods of mathematical economics.* New York, NY: McGraw-Hill.

Chief of Naval Operations. (2008). *Chief of Naval Operations guidance for 2009*. Washington, DC: Government Printing Office.

Corley, R. M. (2009). *Evaluating the impact of the fully burdened cost of fuel* (Unpublished master's thesis, Naval Postgraduate School).

Cotman, R. (2009). FBCF calculator (Version 7) [Computer software]. Washington, DC: Government Printing Office.

Curvin, M. (2011). *M-ATV* [Image]. Retrieved from http://www.marinecorpstimes.com/news/2010/03/marine_latch_032110w

Defense Acquisition University. (2009). *Fully burdened cost of delivered energy—Methodological guidance for analyses of alternatives and acquisition tradespace analysis.* Retrieved from https://acc.dau.mil/fbcfmethod

Defense Energy Supply Center. (2007). FY 2007 standard prices. Retrieved from http://www.desc.dla.mil/default.asp

Defense Energy Supply Center. (2008). FY 2009 standard prices. Retrieved from http://www.desc.dla.mil/default.asp

Defense Energy Supply Center. (2009). *Fact book FY08* (31st ed.). Retrieved from http://www.desc.dla.mil/default.asp

Defense Logistics Agency Energy. (2010). *The Defense Logistics Agency energy fact book Fiscal Year 2010*. Retrieved from http://www.desc.dla.mil/dcm/files/Fact Book FY10 Final Web.pdf

Defense Logistics Agency Energy. (2011). Products and services. Retrieved from http://www.desc.dla.mil

Defense Science Board. (2001). *Report of the Defense Science Board on more capable warfighting through reduced fuel burden.* Retrieved from http://www.acq.osd.mil/dsb/reports/ADA392666.pdf

Defense Science Board. (2008). *More fight—less fuel*. Retrieved from http://www.acq.osd.mil/dsb/reports/ADA477619.pdf

Department of Defense. (2009). *Defense acquisition guidebook.* Retrieved from https://dag.dau.mil

Department of Defense. (2011). *Defense acquisition guidebook.* Retrieved from https://dag.dau.mil

Department of Defense. (2012). *Defense acquisition guidebook.* Retrieved from https://dag.dau.mil

Department of Defense. (2010, February). *Quadrennial defense review.* Retrieved from http://www.defense.gov/qdr/images/QDR_as_of_12Feb10_1000.pdf

Dubbs, S. R. (2011). *Estimating the fully burdened cost of fuel using an input–output model—A micro-level analysis* (Unpublished master's thesis, Naval Postgraduate School).

Duncan Hunter National Defense Authorization Act for Fiscal Year 2009, Pub. L. No. 110-417, Section 332, 122, Stat. 4356 (2009).

Government Accountability Office. (2009a). *Cost estimation and assessment guide*. Washington, DC: Government Printing Office.

Government Accountability Office. (2009b). *Cost estimating guide: Best practices for developing and managing capital program costs*. Washington, DC: Government Printing Office.

Government Accountability Office. (2009c). *Defense acquisitions: Assessments of selected weapon programs*. Washington, DC: Government Printing Office..

Government Accountability Office. (2012). *Defense acquisitions: Assessments of selected weapons systems.* Washington, DC: Government Printing Office.

Hernandez, A., Amara, J. H., Nussbaum, D. A., & Palo, E. P. (2012, October). *Multidisciplinary energy studies support for USMC Expeditionary Energy Office*. Monterey, CA: Naval Postgraduate School.

Hesse, R. (2000). Triangle distribution: Mathematical link for Excel. *Decision Line*, *31*(3), 12–14.

The JASON Group. (2006). *Reducing DoD fossil-fuel dependence*. McLean, VA: Author.

Johnson, N. L., Kotz, S., & Balakrishnan, N. (1994). *Continuous univariate distributions* (Vol. 1, 2nd ed.). New York, NY: John Wiley & Sons.

Leonard, R., Drezner, J., & Sommer, G. (1998). *The arsenal ship acquisition process experience: Contrasting and common impressions from the contractor teams and joint program office*. MR-1030-DARPA Santa Monica, CA: RAND.

LMI Government Consulting. (2007). *Transforming the way DoD looks at energy: An approach to establish an energy strategy*. McLean, VA: Author.

Lockheed Martin. (2011). *F-35B* [Image]. Retrieved from http://www.combataircraft.com/en/News/2011/04/05/Lockheed-Martin-F-35-Flight-Test-Program-Shows-Progress-In-First-Quarter-/

McCullough, A. (2009). *KC-130J* [Image]. Retrieved from http://www.marinecorpstimes.com/news/2009/05/marine_kc130weapons_053009w/

Medium Tactical Vehicle Replacement. (2012). *MTVR Convoy* [Image]. Retrieved from http://en.wikipedia.org/wiki/Medium_Tactical_Vehicle_Replacement

Navy Operational Energy in Acquisition Team (EN-ACQT). (2012). *Energy considerations in AoAs.* Washington, DC: Government Printing Office.

Office of the Assistant Secretary of Defense for Operational Energy Plans and Programs. (2011, May). *Energy for the warfighter: Operational strategy.* Washington, DC: Government Printing Office.

Office of the Assistant Secretary of the Navy for Research, Development, and Acquisition. (2011, June 20). *Energy evaluation factors in the acquisition process* [Memorandum]. Washington, DC: Government Printing Office.

Office of the Secretary of the Air Force. (2009, June 16). *Air Force energy program policy* [Memorandum]. Washington, DC: Government Printing Office.

Office of the Secretary of Defense, Director of Administration and Management]. (2011, May). *Assistant Secretary of Defense for Operational Energy Plans and Programs (ASD[OEPP])* (DoDD 5134.15). Washington, DC: Government Printing Office.

Office of the Secretary of the Navy (SECNAV), Naval Energy Office. (2009). *Naval energy: A strategic approach*. Washington, DC: Government Printing Office.

Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics]. (2007, April 10). *Memorandum for the Deputy Under Secretary of Defense, Acquisition, & Technology*. Washington, DC: Government Printing Office.

Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics (2008, December 8). *Operation of the defense acquisition system* (DoD Instruction 5000.02). Washington, DC: Government Printing Office.

Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics. (2012). *Memorandum for service acquisition executives; Commander USSOCOM.* Washington, DC: Government Printing Office.

Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics] for Acquisition Resources and Analysis/Acquisition Management (ARA/AM). (2008). *Selected acquisition report summary tables*. Washington, DC: Government Printing Office.

Park, S. Y., & Bera, A. K. (2009). Maximum entropy autoregressive conditional heteroskedasticity model. *Journal of Econometrics*, *150*(2), 219–230. doi:10.1016/j.jeconom.2008.12.014

Roscoe, S. A. (2010). *A comparison of the fully burdened cost of fuel methodologies employed across the Department of Defense* (Unpublished master's thesis, Naval Postgraduate School).

Sepe, G. (n.d.). *CH-53E* [Image]. Retrieved from http://georgesepe.com/sikorskyclub.html

Tack, A. (2009). *LVSR* [Image]. Retrieved from http://www.militaryphotos.net/forums/showthread.php?149072-US-Military-Adds-Heavy-Trucks-Under-FHTV-III

Testimony of Chris DiPetto, Office of the Under Secretary of Defense (Acquisition & Technology), before the United States House Committee on Armed Services Readiness Subcommittee, 110th Cong., 3-6 (2008) (testimony of Chris DiPetto).

Truckenbrod, D. R. (2010). *Estimating the fully burdened cost of fuel for naval aviation fixed wing platform* (Unpublished master's thesis, Naval Postgraduate School).

United States Defense Cooperation Agency. (2011). *LAV-25* [Image]. Retrieved from http://www.defencetalk.com/saudi-arabia-requests-light-armored-vehicles-and-support-34909

United States Marine Corps Corrosion Prevention and Control (CPAC) Program Office. (2012). Corrosion prevention and control management tool [Computer software]. Retrieved from http://www.marcorsyscom.usmc.mil/cpac/mgmt_tool.asp

United States Marine Corps Deputy Commandant for Installations and Logistics. (2001). USMC table of organization (TO). Retrieved from http://www.iandl.marines.mil/Divisions/LogisticsPlansPoliciesStrategicMobility(LP)/LifeCycleManagementBranch/Requirements.aspx

United States Marine Corps Expeditionary Energy Office. (2011). *United States Marine Corps expeditionary energy strategy and implementation plan: Bases to battlefield*. Washington, DC: Government Printing Office.

United States Navy. (2009). List of U.S. Navy ships. Retrieved from http://www.navy.mil/navydata/ships/lists/shipalpha.asp

The White House. (2007). *Strengthening federal environmental, energy, and transportation management* (Exec. Order No. 13423, 1-2 C.F.R 3919 (2007)). Washington, DC: National Archives and Records Administration.

Wu, R., & Chen, C. (1990). On the application of input–output analysis to energy issues. *Energy Economics*, *12*(1), 71–76.

XM1091 Fuel/Water Tanker [Image]. (1998). Retrieved from http://www.fas.org/man/dod-101/sys/land/m1091.htm

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